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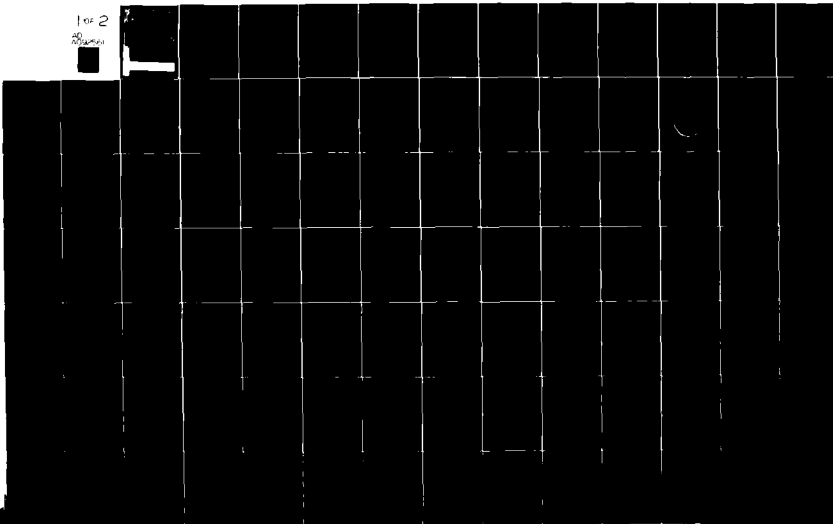

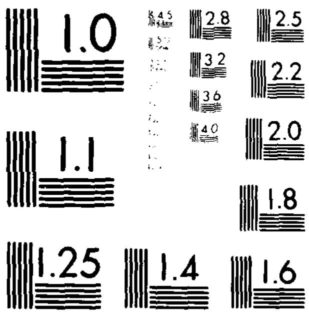

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Technical Report NAVTRAEQUIPCEN 78-C-0076-1

CRITICAL RESEARCH ISSUES AND VISUAL SYSTEM REQUIREMENTS FOR A V/STOL TRAINING RESEARCH SIMULATOR

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October 1980

Final Report June 1978 - June 1979

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NAVTRAEQUIPCEN 78-C-0076-1	2. GOVT ACCESSION NO.: AD-A092 561	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): CRITICAL RESEARCH ISSUES AND VISUAL SYSTEM REQUIREMENTS FOR A V/STOL TRAINING RESEARCH SIMULATOR.		5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report, 15 Jun 78 — 14 Jun 79
		6. PERFORMING ORG. REPORT NUMBER: RTH-0180
7. AUTHOR(s): Robert T. Hennessy, Dennis J. Sullivan, Herbert D. Cooles		8. CONTRACT OR GRANT NUMBER(s): N61339-78-C-0076
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Canyon Research Group, Inc., 741 Lakefield Road, Suite B, Westlake Village, CA 91361		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 63701N, WQ542-PN, 4781-6P2
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Training Equipment Center, Orlando, Florida 32813		12. REPORT DATE: October 1980
		13. NUMBER OF PAGES: 148
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE DEC 4 1980 S C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flight simulators
Flight training
Visual perception
V/STOL
Visual Technology Research Simulator (VTRS)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Critical research issues for Vertical/Short Takeoff and Landing (V/STOL) flight simulator visual systems and the functional requirements for a visual system necessary to support the research were developed. It was concluded from analyses of mission and training requirements that the V/STOL unique tasks, those performed during thrust-borne flight, are the most likely candidates for simulator training. A task analysis was subsequently performed for these tasks to determine the visual information requirements. It became apparent,

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however, that there is no logical way to derive displayed scene requirements from the information requirements and what is known about visual perception. Consideration of general visual requirements for flying, the ecological role of visual perception and the purpose of flight training in a simulator, led to the formulation of four categories of critical research issues. These four categories are: 1) scene content, 2) perceptual learning, 3) use of visual augmentation, and 4) display characteristics.

Four critical research issue summary statements were prepared in order of judged priority of importance for research. Each summary statement defines the topics which can be investigated in the same experiment, the research questions, and the V/STOL task context appropriate for the research.

For example, the first critical research issue summary statement calls for research related to orientation, and distance perception as a function of scene content (detail of ground texture, objects and ground areas), field of view (FOV) size and scene content in the central and peripheral FOV. The recommended task context is decelerating transition and rolling vertical landing in an unconfined area.

The results of performing the recommended research are expected to provide information which will permit specification of the necessary functional characteristics of V/STOL training simulators in terms such as the detail required, FOV size, the best modeling of the scene, the value of augmenting sources of information and advanced training methods.

The functional requirements for a simulator visual system to support the recommended research are specified.

FOREWORD

Vertical/Short Takeoff and Landing (V/STOL) aircraft will almost certainly play an increasingly important role in future military aviation. The specification of V/STOL simulator design characteristics will therefore be an important area of concern for the Naval Training Equipment Center (NAVTRAEQUIPCEN).

The Visual Technology Research Simulator (VTRS) at NAVTRAEQUIPCEN is a research tool that can help to determine the effectiveness of many features of flight simulators, particularly visual system features. As part of the long-range planning for the VTRS research program, it is necessary to determine what research questions, pertinent to the specification of visual systems for V/STOL flight trainers, ought to have the highest priority. This step is best taken well in advance of the actual research, so the VTRS visual system can be properly configured. This study was therefore conducted in order to define the critical research issues as well as the functional requirements for a simulator that will be used to address those issues.

It will become apparent to the reader that, although considered from the V/STOL perspective, the issues discussed are very relevant to trainers for conventional aircraft and helicopters as well. Most are also relevant to trainers for other kinds of vehicles (e.g., ships, tanks, etc.). It will also become apparent that, not only is it difficult and expensive to conduct the research that should be done, but also it is difficult to define the problems in a way that will make clear precisely what research needs to be conducted. This report goes a long way toward that goal, and highlights four areas where behavioral research is likely to have the greatest payoff for the visual systems of future flight trainers.

This is an important report, partly because it addresses itself to the tough issues of visual information presentation. In particular, Sections III, IV and V provide valuable background information, along with a certain point of view, that will be of interest to engineers, psychologists and others concerned with issues of visual realism in flight simulation.

The support of the Naval Air Development Center and Paul M. Linton is gratefully acknowledged for funding this effort under Project W0542-PN-001, Human Factors Engineering Technology Integration and Applications.

Stanley C. Collyer

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Scientific Officer

ACKNOWLEDGEMENT

The authors are grateful to the following individuals and organizations whose efforts and cooperation materially benefited this project.

Dr. Stanley C. Collyer, Human Factors Laboratory, Naval Training Equipment Center, provided thoughtful guidance and many excellent suggestions throughout the course of this study.

Dr. Stanley N. Roscoe, Department of Psychology, New Mexico State University, participated in several phases of this effort and contributed substantially to the work reported here.

The officers of US Marine Corps VMAT-203, Cherry Point, Marine Corps Air Station, provided a great deal of information on the piloting of AV-8A aircraft.

Dr. Paul M. Linton, Naval Air Development Center, contributed much useful information and offered many important comments which aided the authors in the conduct of this work.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (Continued)

SECTION I

OVERVIEW OF REPORT AND COMMENT

OVERVIEW

The objective of this work was to determine what visual system research needs to be done now to obtain information to intelligently specify the visual system requirements for future Vertical/Short Takeoff and Landing (V/STOL) aircraft training simulators. The research issues are those which will have the greatest impact in terms of training efficiency, safety and cost. A second objective is to state the functional requirements for a research visual system for a V/STOL simulator which will support the critical issue research. The work reflected in this report consisted of three basic parts.

Analyses were performed on V/STOL mission, training and accident information to determine visual information requirements and V/STOL tasks which are likely candidates for simulator training. Mission and training requirements for present and future V/STOL aircraft were analyzed to determine the mission and environmental contexts of V/STOL flight tasks. A review of previous V/STOL accident analyses and an analysis of recent accident summary information for the AV-8A were performed to determine the V/STOL flight tasks that, in the interest of safety, should be trained in a simulator. A detailed task analysis of V/STOL flight tasks was then performed to determine the specific actions required of a V/STOL pilot and which of those actions are dependent on information from the out-of-cockpit visual scene. The kinds of visual information required for each of the V/STOL unique tasks were then elaborated in tabular form. The report of this part of the work is contained in Section II.

Concurrent with the above efforts, literature on visual simulation and visual perception was reviewed to discover what research has been done on visual simulation requirements and what characteristics of visual perception appear to be relevant to visual simulation.

Section III contains some introductory thoughts on the requirements for flight simulators, flying behavior and flight training. Visual simulation requirements are found to be uniquely difficult to specify because, unlike other aspects of flight simulation, there is no mediation between the pilot and the effects produced by the environment. Also, it is pointed out that flight training instruction emphasizes the acquisition of control skills with little formal instruction on information acquisition, i.e., perceptual, skill acquisition. Opportunites for improving training by giving some attention to perceptual learning are missed.

Section IV discusses some aspects of the visual simulation and visual perception literature. The main conclusion from the literature review was that there is very little information in the literature that is helpful to the development of visual simulation requirements. A summary of some characteristics of perception relevant to the support of purposeful behavior, such as flying, are presented.

It became apparent after the visual information requirements for V/STOL tasks had been tabulated and the literature reviewed that translating visual information requirements into simulator visual system characteristic and content requirements by some logically defensible and systematic process was not readily possible. Visual system requirements in general appear to be the result of highly subjective judgements based on accepted past practices.

The third part of the work performed was formulation of the critical research issue statements and the the visual simulation system requirements to support the research. The critical research issue topics are divided into four categories: a) visual scene content topics, b) perceptual learning topics, c) augmentation topics and d) visual display characteristics topics. The importance of each topic as a subject for research is discussed. The individual topics, across categories, were selected on a priority basis to form aggregates of topics which can be addressed in the same experiment. These aggregates of topics along with the questions to be answered through research, and the task and environmental contexts, are summarized in the form of four critical research issue statements. Discussion of the critical research issue topics and the critical research issue summary statements are presented in Section V.

The functional requirements for a V/STOL research simulator visual system that are necessary to support the research recommended in the four summary statements are presented in Section VI.

COMMENT

The purpose of this study was to identify critical research issues that should be investigated to eventually allow procurement of simulators with visual systems that meet all the training objectives for V/STOL aircraft for which they are intended at the lowest cost. There is no question that research is necessary to determine what are the required characteristics of a simulator visual system. However, the visual system is only one part of a simulator and a simulator is only a tool to aid flight training, albeit an important one. Through the course of reviewing the literature pertinent to this work it became apparent that many review and research papers have stressed that good training techniques must be used to derive the maximum benifits from a well designed simulator. A good tool is effective only when it is properly used.

It also became apparent that the knowledge of vision and perception embodied in the literature is not very useful for determining what should be the nature of the visual scene in a flight simulator. Perception is a poorly understood behavior. Psychophysical factors are only a small part of the process of perception but have received more basic research attention than any other aspect of perception. For important practical applications, such as simulator flight training, knowledge of how perception operates in the complexity of the real world to serve purposeful behavior is urgently needed.

Doing research on a complex topic, such as perception, in a complex environment, such as flying, is not easy nor comfortable. There are too many uncontrolled things going on, and complex behavioral topics defy quantitative description. Research is supposed to be the making of educated guesses (formulating hypotheses) and trying to confirm or disprove the guesses. Too often research turns out to be confirming what is fairly certain to be so.

An attempt was made in this report to identify critical research issues for visual simulation that really seem to be important issues with little regard to their amenability to objective description. Most of the issues are aimed at the more complex aspects of perception, i.e., what characteristics of a scene significantly affect the ability of a pilot to acquire information and how changeable, through training or inadvertently, are a pilot's perceptual abilities? These are researchable topics which have important implications for visual simulation. The variables of these issues cannot be neatly described but that is only an indication of how poorly understood they are.

A few points to bear in mind while reading this report are:

1. There are issues other than visual and not addressed in this report involving the use of simulation which are of importance to V/STOL flight training, e.g., the nature of the training program and how the simulator can be optimally used in the training program. These issues also are deserving of research but are not considered here because they do not directly affect visual simulation issues.

2. The visual research issues addressed here are primarily related to simulator training of V/STOL piloting tasks but the outcome of the research is likely to have some application to the simulator training of piloting tasks for Vertical Takeoff and Landing (VTOL) aircraft and, perhaps, for Conventional Takeoff and Landing (CTOL) aircraft.

3. In general, visual research issues can be divided into psychophysical issues and perceptual issues. The distinction is that psychophysical issues are concerned with very low order, or early, discrete, processes of vision while perceptual issues are concerned with high order, or late, integrative processes of vision. The perceptual issues, which are emphasized in this report, are considered to be more important and more deserving of research than the psychophysical issues because:

a) What is perceived most directly and immediately affects a pilot's thinking and behavior.

b) There appears to be sufficient enthusiasm and planned research for investigating psychophysical issues. This is at least partially due to the fact that many psychophysical characteristics and simulator visual system characteristics are described in the same terms and are therefore more tractable. Perceptual characteristics are more remotely related to simulator visual system characteristics and the relationships are more complex.

c) Psychophysical sensitivities and characteristics are reasonably well understood and documented. Furthermore, they are relatively easy to study using conventional research techniques. Perceptual phenomena are not well understood nor are they as easy to study as psychophysical characteristics.

SECTION II

V/STOL FLYING, MISSIONS, TRAINING, ACCIDENTS, TASK ANALYSIS AND INFORMATION REQUIREMENTS

INTRODUCTION

The purpose of this work is to determine the critical visual system research issues and to specify the characteristics of a V/STOL resarch simulator visual system to support the research. To achieve this purpose it is necessary to have a reasonable idea of the nature of V/STOL piloting tasks which are most suitable for training in a V/STOL simulator and to identify the characteristics of the visual information that a pilot is expected to acquire from the external scene.

The content of this section is almost exclusively based on the experiences of the U.S. Marine Corps with the AV-8A aircraft. The reader is therefore cautioned that future uses of V/STOL aircraft by the U.S. Navy may be different from the current uses by the U.S. Marine Corps.

The V/STOL piloting tasks set the operational contexts in which the visual system research is to be conducted. Descriptions of the piloting task include the general mission and environmental characteristics in which V/STOL tasks are performed as well as the manuevering requirements and aircraft control requirements the pilot is expected to fulfill.

The information that the pilot must acquire visually from the external scene must be specified as a basis for determining what a simulated visual scene must contain to afford the required information to the pilot.

The principal conclusions of this section are what V/STOL tasks are likely to be trained in future simulators and the visual information the pilot needs to acquire to perform his tasks. These conclusions are reached by consideration of the V/STOL piloting task in general, specific V/STOL piloting tasks, V/STOL mission requirements, current V/STOL training practices, V/STOL accident information, and the visual information requirements for specific V/STOL aircraft control tasks.

V/STOL FLYING

A V/STOL aircraft has the ability to take off and land vertically or with a very short ground-roll as compared to conventional aircraft. Helicopters are usually considered to be V/STOL aircraft. In this report, however, V/STOL will refer to vertical/short takeoff and landing aircraft other than helicopters.

V/STOL aircraft have unique flight characteristics and place unusual demands on the pilot. The following two sub-sections describe general V/STOL aircraft characteristics and the nature of V/STOL piloting tasks. Both sub-sections are taken verbatim from Ringland (1977) who provides an excellent introduction to V/STOL technology as it affects the pilot's role.

General Characteristics Of V/STOL Aircraft

"The V/STOL aircraft is capable of generating lift greater than its weight at zero forward speed. In accordance with the general requirements for all aircraft, it must be safe and easy to fly and economical to operate in its intended mission. It has a means for generating high static thrust in the vertical direction; its thrust-to-weight ratio is greater than one, in contrast to most CTOLs where this ratio is less and sometimes considerably less than one.

"After leaving the ground in the VTO mode, the V/STOL must have a means for directing its thrust in the horizontal direction for forward flight. This must be possible in a progressive fashion as the aircraft accelerates from a hover. If the V/STOL has fixed wings (i.e., all V/STOLs except helicopters wherein the "wing" is in continuous rotation with respect to the aircraft), it accelerates to purely wing-borne flight, where it uses the thrust only for propulsion. That portion of its flight between hovering or thrust-supported flight and purely wing-borne flight is termed transition or conversion flight.

"Finally, the V/STOL must have a control system permitting the pilot to maintain an equilibrium balance (trim) among the forces and moments acting on the aircraft and to control attitude, path, and speed throughout hovering, transition (conversion), and wing-borne (conventional) flight. Such systems are relatively complex compared to the case for a CTOL because of the wide range in speeds and the relative lack of inherent stability characteristics at low speeds. Conventional control surfaces rely on the relative motion between the aircraft and the air through which the aircraft moves to generate both stabilizing and controlling forces and moments. At zero airspeed, these are absent, and the propulsive lift system must be used to generate some or all of the necessary forces and moments.

"V/STOLs lack inherent stability qualities at low speeds, not only because conventional stabilizing surfaces are ineffective, but also because operation of

the active lift systems (downward-directed thrust) typically involves destabilizing tendencies. Such tendencies include ground effects, which are the forces and moments acting on the hovering V/STOL which are caused by the interaction of the downward-directed gas flow with the ground. Hot Gas Ingestion (HGI) is another problem; the engine loses thrust or power because it ingests some of its own exhaust gases. This condition usually takes some time to develop and depends on the prevailing wind and aircraft height above ground. Other attitude disturbances come about through the reaction forces produced by altering the direction of high-velocity air flow as it enters, flows through, and leaves the aircraft. The flow turning forces are sometimes given special names, e.g., intake momentum drag, and will depend in part on the airflow conditions external to the aircraft.

"These forces and moments can overpower whatever conventional stabilizing forces are present at low forward speeds. The result is that equilibrium must be restored by the pilot or by automatic devices acting through the V/STOL's flight control system. This is in marked contrast to most CTOLs where greater reliance can be placed on the inherent aerodynamic properties of the aircraft to maintain trim." (Ringland, 1977, pp. 5-6.)

The Pilot's Role In V/STOL Flying

"The pilot's role in flying the V/STOL aircraft consists of a number of functions, all of which have their counterparts in conventional aircraft. They can be briefly listed as follows:

1. Configuration scheduling; lift/thrust management
2. Attitude stabilization
3. Path, speed, and position control or regulation
4. Subsystems management

Each of these functions is, however, more demanding than the counterpart in conventional aircraft. The pilot has more things to control which are changing faster and which must be attended to in shorter periods of time.

"Excessive demands on the pilot are in large measure a consequence of characteristics inherent in the V/STOL concept. Indeed it quite often happens that quite dissimilar V/STOL configurations exhibit strong similarities in behavior in response to the controls because of similarities in the underlying physics governing the aircraft's motions. This is why the workload problem and the pilot's role can be addressed, at least in part, without configuration-specific considerations.

"Configuration Scheduling. During a landing approach, for example, the pilot desires to maintain a desired flight path while the configuration and airspeed are changed for landing (gear, flaps, throttle setting, etc.). In the V/STOL the changes in thrust angle and magnitude are much more profound, and typically result in "ballooning" above the desired glide slope upon initiating conversion. Both path (or altitude) and speed changes the result from changes in pitch attitude, throttle setting, and thrust angle; the appropriate technique which accomplishes the deceleration while minimizing the path disturbances and maintaining flight safety is relatively complex, and usually the result of carefully worked out sequential procedures. The "flexibility" provided by the redundant controls is lost in the necessarily restrictive procedures required for lift and thrust management during transition.

"Stability and Controllability. More aircraft degrees of freedom must be stabilized and controlled than are typical for conventional aircraft. In the conventional flight regime, the pilot's control of vehicle attitude is usually sufficient to guarantee stability of the motions in the translational degrees of freedom -- lateral drift, forward speed, and rate of climb or descent. In V/STOL aircraft in transition or hovering flight, attitude control is insufficient more often than not; the translational motions do not "take care of themselves," are often unstable in their responses, and require more precise control to execute the desired maneuver (e.g., landing on the moving deck of a ship). The rotational motions, that is, motions in pitch, roll, and yaw, can also be unstable in their responses, particularly when the aircraft is in close proximity to the ground. The causes here have already been noted: flow turning forces and moments in the lift/propulsion system; and ground effects caused by the interaction of high velocity downward flow with the ground.

"A helicopter in hover is statically stable in attitude because the center of lift, the rotor, is above the center of gravity. It is frequently dynamically unstable in attitude in that pitch or roll oscillations will exhibit increasing amplitude with time unless the pilot intervenes. If the rate of amplitude increase is not too rapid, he can control or dampen the oscillations to an acceptable amplitude.

"A hovering jet-lift V/STOL, on the other hand, is neutrally stable, perhaps even statically unstable, in attitude; the center of lift is coincident, perhaps even below, the center of gravity. The divergent

tendency may be aggravated by ground effects or flow turning moments. The pilot must detect and correct the divergence early; if he does not, he may run out of control power and be unable to recover control. The situation is something like balancing a broomstick on end. It is easy to recover if the broomstick is long (slow divergence) and it is not allowed to tip or fall too far, and difficult if the broomstick is short (rapid divergence).

"Stability in the linear degrees of freedom assume greater importance in V/STOLs relative to conventional airplanes. In contrast to CTOLs altitude motions are controlled separately; recall the earlier discussion of the relative stability of vertical motions in a low disk loading helicopter versus the high disk loading or fan-lift V/STOL. The translational motions are also important, particularly in hover. These motions (displacements from a desired landing spot) are, at best, neutrally stable; there is no inherent tendency to return to the desired landing spot in the absence of pilot intervention. Since these motions are often controlled by attitude, the responses of which often exhibit deficient stability, it can be appreciated that precision hover is a very demanding task -- particularly in gusty conditions or in the presence of destabilizing ground effects (e.g., suckdown or loss of lift close to the ground).

"In summary, past V/STOL aircraft designs have exhibited one or more deficiencies in stability, controllability, and sensitivity to disturbances, particularly when judged in a context of a demanding piloting task such as decelerating, descending precision instrument approach and landing, perhaps on the moving deck of a ship. Under such circumstances, "squirreliness" in responses, requirements for precise coordination of a number of manipulator deflections, or excessive responsiveness to factors in the external environment severely compromise the pilot's ability to carry out his flying tasks." (Ringland, 1977, pp. 33-35.)

V/STOL Unique Flight Phases

Figures 1 and 2 show typical V/STOL flight profiles for landing aboard an amphibious warfare ship, an LHA, and at a forward site. These figures give a good impression of how V/STOL landings differ from those of CTOL aircraft. The basic approach pattern for the two types of aircraft is similar, but the task performance requirements are very different for V/STOL aircraft than for CTOL aircraft.

An initial circling of the ship or landing area is performed by the V/STOL pilot for two purposes. First it allows the pilot to identify visual reference points he will use during the approach and landing. This inital view of the landing area and the surround is particularly important for forward site operations where the landing area may be totally unfamiliar. Second by circling the ship or landing area it permits the pilot to set up a standard position, altitude and airspeed on his downwind leg which become the beginning conditions for the execution of the sequence of control procedures leading into the transition from wing-borne to thrust-borne flight and ending with the landing.

The V/STOL pilot must coordinate his control not only of roll, pitch, yaw and power but also of thrust vector to achieve the desired attitude, position and descent rate. Since all the control variables interact, the pilot must be concerned not only about achieving a particular aircraft state or flight profile but also with what control actions he uses to achieve it.

Near the termination of the landing approach, at low airspeed, attitude control of the V/STOL aircraft depends on reaction applied in a particular direction. At low airspeeds the control surfaces of the aircraft are ineffective. Since reaction controls "steal" power from the main thrust vector, the pilot must use them judiciously. Overcontrol during thrust supported flight can result in undesired settling or attitude changes.

Additional factors which impact on the V/STOL landing tasks are the gross weight and stores configuration of the aircraft. The handling characteristics of the aircraft will change as a function of weight and configuration. The pilot must take these factors into account both during pre-mission planning and during the actual execution of the takeoff, transition and landing tasks.

Because of the inherent instability of V/STOL aircraft during thrust-borne flight the pilot must be sensitive to the development of attitude drifts and sideslip movements and must make corrections before an unrecoverable situation develops.

Considering the control demands placed on the pilot to achieve a V/STOL landing, it is apparent why it is highly desirable to standardize both the beginning state of the aircraft, i.e., position, altitude and airspeed for the approach and the subsequent execution of the approach and landing as illustrated in Figures 1 and 2.

During takeoff, the V/STOL pilot must cope with similar control task demands. Use of standard takeoff procedures to the extent possible, is again, a means of reducing the work load of the pilot by reducing the variations that he must deal

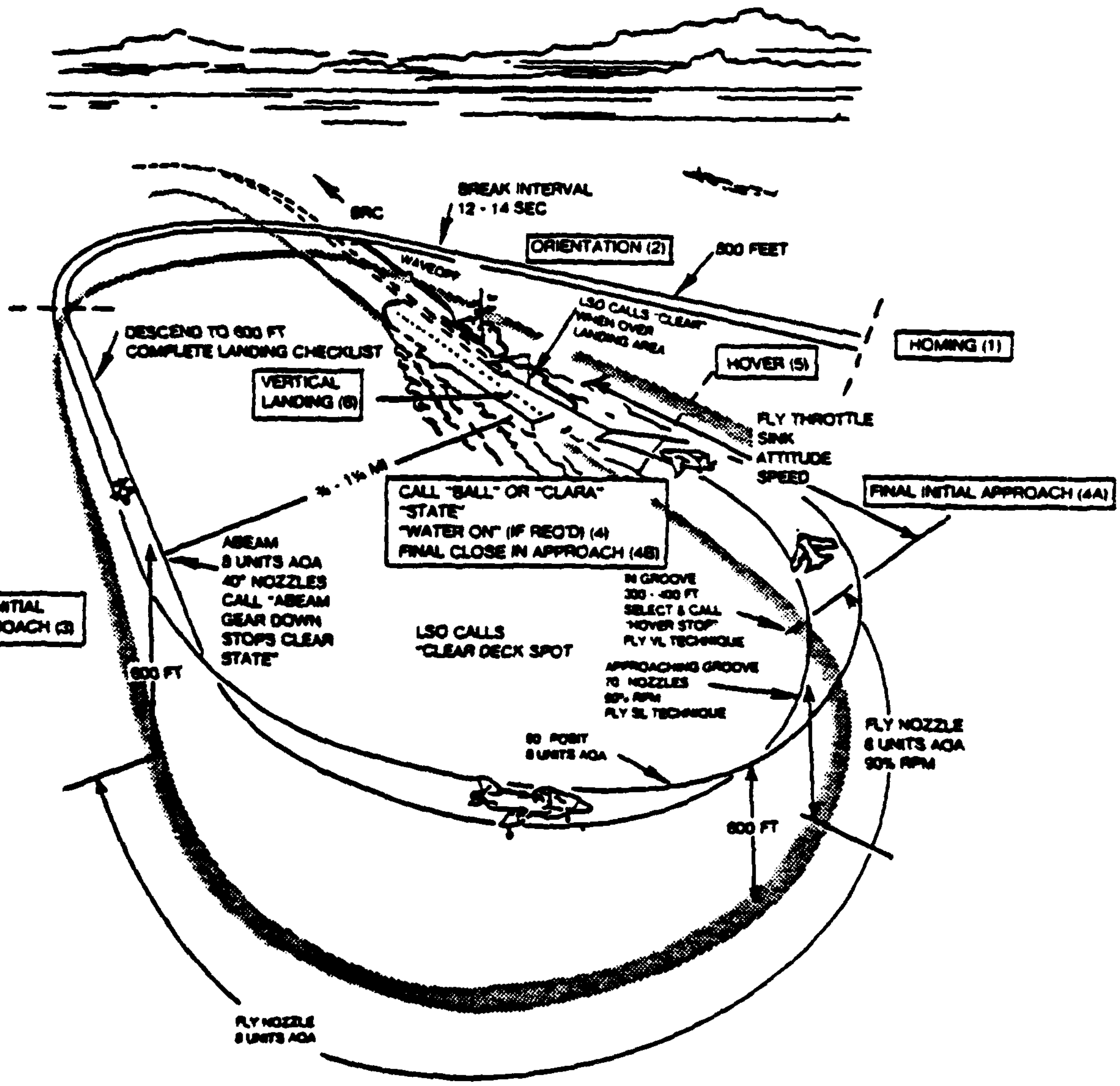

Figure 1. Typical VFR ship landing pattern. (From Naval Air Systems Command, 1976, as modified by Quanta Systems Corp., 1979.)

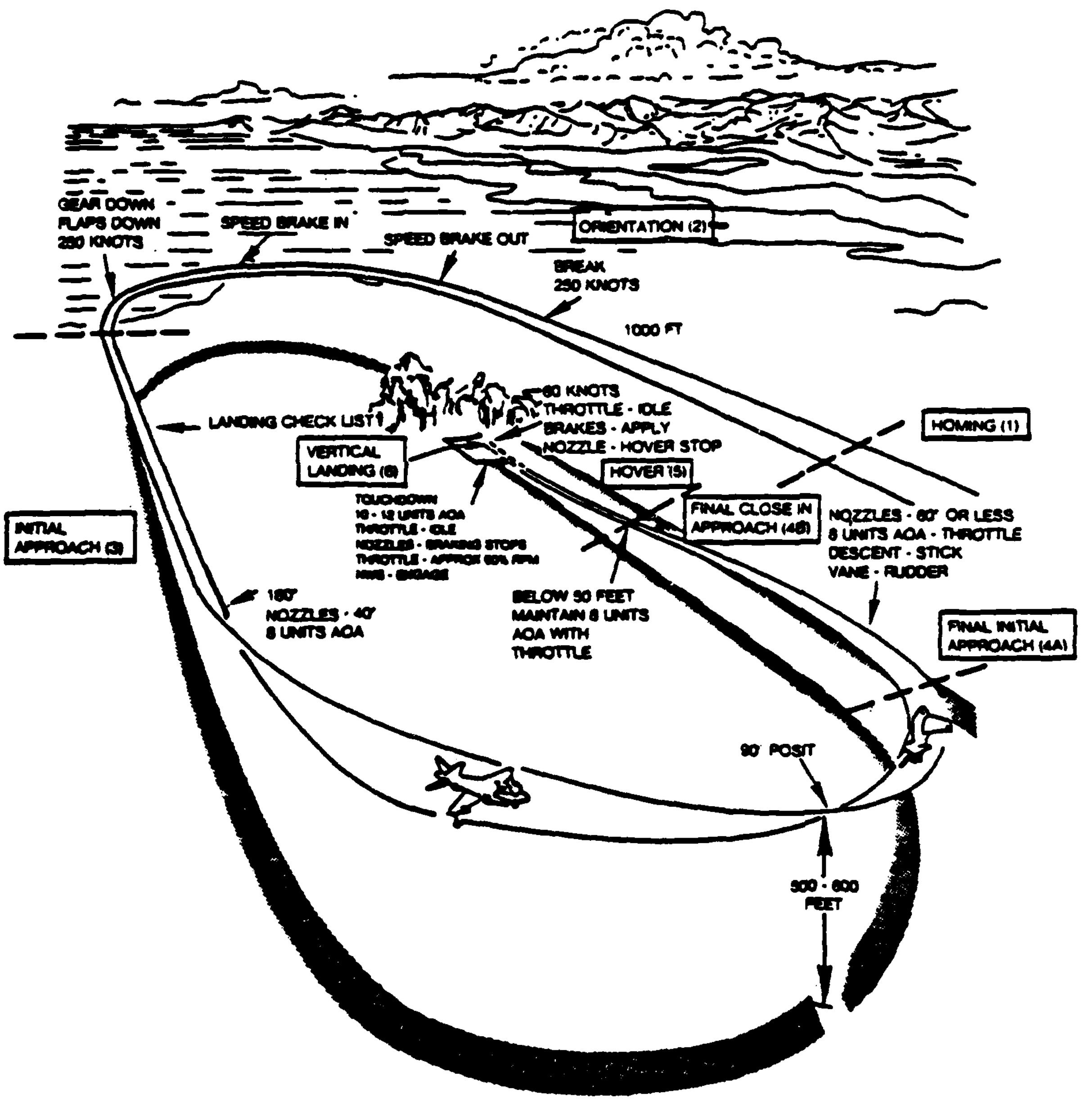

Figure 2. Typical VFR forward site landing pattern. (From Naval Air Systems Command, 1976, as modified by Quanta Systems Corp., 1979.)

with; that is, it is desirable to have standardized procedures for both landing and takeoff that in effect define a desired flight profile. The pilot's task therefore becomes one of maintaining a desired profile and coping with deviations from this profile. The pilot knows what he wants to do and when, and having learned the control techniques and procedures, he can perform them in a reasonably automatic fashion. Most of the attentional demands placed on the pilot will therefore be in dealing with imposed variations in the profile and not in deciding what the profile should be. Standardization of procedures is applied to CTOL aircraft for the same purposes but, because the work load demands on the V/STOL pilot are so much greater, the use of standard procedures is much more important. The implications of standardized procedures in regard to pilot information requirements and simulator visual system requirements will be discussed toward the end of this section.

V/STOL (AV-8A) Takeoffs And Landings

V/STOL aircraft, as exemplified by the AV-8A, employ eight distinct takeoff and landing procedures. These are: 1) vertical takeoff (VTO), 2) rolling vertical takeoff (RVTO), 3) short takeoff (STO), 4) conventional takeoff (CTO), 5) vertical landing (VL), 6) rolling vertical landing (RVL), 7) slow landing (SL), and 8) conventional landing (CL). All takeoffs except the conventional takeoff require a transition from wing-borne to thrust-borne flight. All landings except the conventional landing require a decelerating transition from wing-borne to thrust-borne flight. The NATOPS Flight Manual (Naval Air Systems Command, 1976) for the AV-8A details the standard operating procedure for the different takeoff and landing types and accelerating and decelerating transitions. To gain some understanding of the V/STOL unique piloting task it is worth describing some of the task procedures as given in the NATOPS Flight Manual.

Vertical Takeoff. A VTO is used when the aircraft is light enough and the characteristics of the takeoff area do not permit one of the other takeoff types. The general procedure is to apply sufficient power to cause the aircraft to rise straight vertically to 25 feet or more above the surface. The NATOPS Flight Manual comments that lateral control during the first few feet of a VTO is critical. The pilot is told not to hesitate to make immediate, large and rapid control movements to counteract yaw and roll. If the pilot is unable to arrest or eliminate yaw and/or roll, he should land the aircraft by reducing power if significant lateral velocity (sideslip) has not developed. During the VTO the pilot is told to maintain his scan primarily in the straight ahead direction and to hold his heading and attitude constant during lift-off. After achieving altitude above 25 feet the pilot should either reduce power to maintain a hover or gradually deflect the nozzles to transition to forward flight.

Pilots from VMAT-203, the U.S. Marine Corps AV-8A Training Squadron, located at the Marine Corps Air Station, Cherry Point, North Carolina, said that the control of bank angle and, consequently, lateral translation is critical when the AV-8A is near the ground. If any significant bank angle or sideslip develops the aircraft will quickly go out of control. Several pilots mentioned that during a VTO or while maintaining a hover they will look to the side. Other pilots reported that they maintain the straight ahead scan as recommended by the NATOPS Flight Manual.

Rolling Vertical Takeoff. An RVTO permits takeoff with a gross weight in excess of the VTO limit. An RVTO requires approximately 100 feet of ground roll and 500 feet of distance to clear a 50 foot obstacle. Because of the necessity to not allow sideslip it is recommended that an RVTO be made as nearly into the wind as possible. The NATOPS Manual instructs the pilot to hold the heading and attitude constant on liftoff and to monitor and adjust heading for sideslip during transition. After takeoff the pilot is to commence transition to forward flight.

Short Takeoff. An STO is made when the aircraft gross weight is too high for any other type of takeoff including a CTO. Depending on the weight of the aircraft and density altitude a ground roll of from 200 to 2000 feet might be required. The NATOPS Flight Manual instructs the pilot to maintain attitude and heading and to adjust heading to compensate for any sideslip. The STO leads directly into the transition to forward flight.

It should be recognized that to execute a short takeoff requires a great deal of pre-mission planning. The pilot must consider factors of hover weight and density altitude and must then compute appropriate nozzle angle and nozzle rotation speed. This information coupled with knowledge of the strength and direction of prevaling winds is used to compute the required ground roll and distance for obstacle clearance. Maintenance of the proper Angle-Of-Attack (AOA) is critical.

Conventional Takeoff. The conventional takeoff for the AV-8A has the same general characteristic as a takeoff of a CTOL aircraft.

Accelerating Transition. The NATOPS Flight Manual advises the pilot that an accelerating transition is made when clear of ground effect "above 25 feet" and at an altitude sufficient to avoid obstacles. During the accelerating transition full power is used, attitude is held constant and the nozzles are gradually rotated to the aft position. AOA must be monitored and not allowed to exceed a limit value.

During the accelerating transition the pilot is attempting to maintain a constant attitude and a slight climb if possible. As his airspeed increases he gains lift from his wings and becomes less dependent on lift from thrust. As wing lift increases the pilot will rotate the nozzles progressively aft to gain airspeed. Too rapid a nozzle rotation during the accelerating transition will cause the climb rate to diminish, or worse, the loss of altitude. During the accelerating transition the pilot must closely monitor sideslip. During a VTO or STO, at low airspeeds avoidance of sideslip is critical. As airspeed increases during accelerating transition the pilot is still required to monitor and correct sideslip with heading changes. As a pilot gains airspeed and altitude, sideslip diminishes in importance.

Decelerating Transition. Except for a CL, a decelerating transition from wing-borne to thrust-borne flight is necessary. According to the NATOPS Flight Manual, the decelerating transition starts from a key position approximately three quarter to one nautical mile from the touchdown point at an altitude of 200 feet above the ground. The key is approached in level or very slightly descending flight and, at the key position, the nozzles are rotated downward. After departure from the key, the pilot is advised to maintain attitude, minimize sideslip and increase power as required to control the rate of descent, to arrive at the landing site at a height of approximately 50 to 60 feet above the ground "if a VL is to be executed". When the aircraft reaches approximately 50 knots the pilot is advised to visually select ground references, and flare slightly to stop. If a rolling landing is planned, forward speed is approximately 30 to 50 knots at touchdown.

As in the accelerating transition the maintenance of attitude and the control of slideslip are critical. The pilot, using his nozzle controls and power and attitude controls, makes a shallow, smooth descent while gradually reducing airspeed.

Vertical Landing. The VL is commenced from a height of 50 to 60 feet above the ground. The NATOPS Flight Manual advises the pilot to start a slow descent by reducing power, monitor ground references and maintain heading and attitude except for necessary corrections for drift. When the aircraft enters ground effect at approximately 20 to 25 feet above the ground the pilot is to expect some turbulence and trim changes. At this point the pilot should maintain a positive rate of descent until the ground is reached and should avoid stopping in ground effect.

Rolling Vertical Landing. An RVL is essentially the same as a Vertical Landing except that a small forward airspeed of approximately 30 to 50 knots is maintained. The RVL can be entered from a hover which is established short of the intended

touchdown point or may be entered directly from the decelerating transition. The main purpose of the RVL is to avoid damage to the landing surface from the engine exhaust or to avoid ingestion of ground debris. The NATOPS Flight Manual advises the pilot to control his airspeed with pitch and his descent rate with throttle. Before entering ground effect, approximately 20 to 25 feet above the ground, the pilot is to flare the aircraft to landing attitude.

Slow Landing. The SL is used when the aircraft gross weight is too high for a VL or a RVL or to reduce engine stress. Performance calculations are required for heavy gross weights of the aircraft or for use of landing strips less than 500 feet in length. The approach speed will depend also on the gross weight and power used during the approach. When the aircraft is abeam of the landing area on the downwind leg, the nozzles are rotated to 40 degrees, which begins a deceleration. After a turn of 45 degrees toward the final leg the nozzles are rotated to 70 degrees downward. When the aircraft is near the touchdown point and approximately 30 to 50 feet above ground level the pilot is to control the descent by reducing power and allow the angle-of-attack to increase to a certain limit until touchdown occurs. Typically touchdown speed for the AV-8A in an SL will be greater than 60 knots. A variation of the slow landing where less manipulation of the nozzles is involved is advised by the NATOPS Flight Manual for use during some emergencies and familarization training. The stated purpose of the fixed nozzle SL is to reduce pilot workload.

Conventional Landing. A conventional landing in the AV-8A requires a runway length of between 6000 to 8400 feet. A CL uses a maximum of a two and one half degree glide path. For the AV-8A the CL has a relatively high touchdown speed, generally about 160 knots.

Landing Aboard Ships. Shipboard landings will almost always involve coming to a hover (matching ship's speed) astern of the ship, or maintaining a small forward speed, after a decelerating transition. Once hover is achieved the aircraft will advance around the port side to the touchdown point and execute a Vertical Landing. Stern boardings, whether by VL or by RVL are atypical but possible.

For all types of takeoffs and landings which involve thrust-borne flight the amount of time in thrust-borne flight is kept to a minimum because of the high rate of fuel use.

V/STOL MISSION, TRAINING AND ACCIDENT ANALYSES

Analyses of the mission and training requirements for existing and proposed V/STOL aircraft and missions were conducted to identify the number, type and relevant characteristics of V/STOL flight maneuvers involving external visual references. Accident information was analyzed to

determine if particular V/STOL flight activities are unusually hazardous. The goal of these analyses was to establish which flight tasks, for reasons of mission importance and/or safety, are likely candidates for training in future V/STOL simulators.

Mission Analysis

Missions are categorized according to whether a subsonic, multi-mission or a supersonic, fighter/attack type V/STOL aircraft would be appropriate. These two types are referred to, repectively, as Type-A and Type-B V/STOL although these terms are no longer used by the Navy. The Navy is now considering V/STOL developments only in terms of generic performance characteristics.

Mission analysis data for Type-A V/STOL aircraft were taken from the conceptual studies conducted by, and for, the U.S. Naval Air Development Center (McDonnell-Douglas Corporation, 1978; Andrews, 1975). The mission requirements for the Type-A V/STOL are basically those of the aircraft that a Type-A V/STOL might be expected to replace. The mission analyses for the Type-B V/STOL are partially based on anticipated future requirements but, because of availability and detail of published mission requirements, rely on the AV-8A and AV-8B aircraft performance.

Type-A V/STOL Missions. Concepts for Type-A V/STOL aircraft have been developed in terms of current technology. They reflect the requirement for an aircraft capable of tactical applications equivalent to those of the present S-3A and E-2C. The same aircraft may also be capable of replacing the CH-46 for tactical support and carrier based utility/delivery aircraft. In addition to having the space/payload capacity to meet the mission requirements of the above listed aircraft, Type-A V/STOL aircraft are likely to be able to operate from short runways and/or to takeoff and land vertically from both shore and ship. Only current concepts of operation, and functions employed in fleet Anti-Submarine Warfare (ASW), Anti-Electronic Warfare (AEW) or utility/delivery have been included under Type-A V/STOL missions.

Mission definition - ASW. For ASW systems the mission requires the search, detection, classification, localization and attack of submarines. Specific ASW missions to be undertaken by a Type-A V/STOL ASW aircraft would include:

- Convoy Escort
- Harass/Hold Down
- Area Search
- Contact Investigation
- Reconnaisance
- Area Coordination

With one exception, ASW missions will not require any V/STOL-unique performance or characteristics . That exception is that operational Type-A V/STOL aircraft will be launched and recovered from carriers, medium-sized ships such as LPHs and LHAs, and eventually small, aviation capable ships. Both vertical and short takeoffs and landings can be anticipated aboard medium and large sized ships. Only vertical takeoff and landings will be possible on small aviation capable ships. The launch and recovery of Type-A V/STOL aircraft will be affected by the high gross weight of the aircraft, the nature of the cockpit geometry and the high pilot workload that V/STOL flight imposes.

Mission definition - AEW. For AEW systems the missions require maintaining surveillance over wide areas of airspace and ocean surface using active and/or passive sensors. Specific AEW missions to be undertaken by V/STOL aircraft would include the following missions:

- Surveillance
- Target Detection & Tracking and Plotting
- Airborne Command Post
- Information Relay & Control
- Rendezvous-Refueling

The generalized AEW mission profile would be quite similar to ASW profile with the exception that the low altitude segments would not be required. As with the ASW missions discussed previously, the AEW missions to be performed by Type-A V/STOL will not require any V/STOL-unique performance or characteristics with the exception of launch and recovery. AEW configured Type-A V/STOL aircraft will be launched and recovered aboard carriers, medium-sized ships and small, aviation capable ships. The launch and recovery characteristics for AEW will be the same as for ASW.

Mission definition - utility/troop carrier. For utility/ troop carrier systems the missions require an aircraft capable of moving a reasonable volume of cargo and/or number of personnel from ship to shore and vice-versa. The characteristics of the missions for Type-A V/STOL aircraft, configured for utility/troop carrier operations, which will drive aircraft design are the requirements for vertical and short takeoffs and landings at minimally prepared shore sites and upon carriers and medium-sized ships. Similar problems to those of Type-A V/STOL AEW/ASW configured aircraft with respect to fuel consumption, gross weight, cockpit geometry and pilot workload can be expected for utility configured aircraft.

Summary of Type-A V/STOL mission requirements. Type-A V/STOL missions and the avionic concepts for the AEW/ASW missions to be accomplished by those aircraft do not appear to impose any V/STOL-peculiar requirements on the pilot other than

those associated with shipboard launch and recovery and shorebased takeoff and landing. Those phases of flight peculiar to thrust-borne aircraft operations (e.g., hovering, transition, landing and takeoff) will be those requiring specific attention in this effort. Whether the presence of a co-pilot will be necessary to reduce pilot workload during these phases of flight, and what a co-pilot's tasks would be has not been determined. Some multi-crew suggestions favor a pilot-right seat/co-pilot-left seat cockpit configuration, but even this aspect of aircraft design is not firm.

A preliminary analysis (General Electric, 1977) of the avionics configurations of Type-A V/STOL concepts configured for ASW and AEW roles does not indicate any V/STOL-unique equipment requirements (e.g., none of the avionics systems identified as necessary for AEW/ASW mission accomplishment require thrust-borne flight). However, because all V/STOL can be expected to have very high fuel consumption in hover, and the ASW/AEW mission profiles require long on-station times some method of minimizing landing fuel requirements must be attained. Past thinking suggested that a steep decelerating approach to a hover with a minimum amount of time in the hover mode while maneuvering to the touch-down point would be one way to reduce fuel requirements.

As an ultimate goal Type-A V/STOL aircraft should be capable of landing under zero ceiling and 700 feet visibility conditions. This goal, while not presently achievable is the direction of the Navy Vertical Takeoff and Landing (NAVTOLAND) program (Advanced Developments Projects Office 1976, 1978).

Type-B V/STOL Mission. While some concept development efforts for Type-B V/STOL had been undertaken, the Navy's V/STOL research and development program has been limited to the USMC AV-8A and AV-8B. The AV-8A is the only V/STOL aircraft on which a backlog of operational experience has been accumulated. The AV-8A and AV-8B are both powered by a single engine having rotatable nozzles for the control of thrust angle. Control of vehicle attitude in the hovering and conversion (from aerodynamic to thrustborne flight) flight regimes is by means of a reaction control system driven by bleed air from the engine.

Possible future Type-B V/STOL aircraft can be expected to have mission requirements which encompass and exceed those of the AV-8A. Type-B V/STOL is generically a supersonic fighter/attack type aircraft with the capabilites to operate from carriers, medium-sized ships such as LPHs and LHAs, possibly small, air-capable ships (such as DD 963s) and small, unimproved pads near the forward battle area. Future Type-B V/STOL would not be expected to enter the Navy or Marine inventory until the 1990s. One source of mission information for Type-B V/STOL likely will be the projected mission requirements for the AV-8B.

Mission definition - attack. Analyses of the mission requirements for the AV-8B were made to discover the number, type and relevant characteristics of V/STOL flight maneuvers involving external visual reference. The mission analysis is based on a recent mission analysis for the AV-8B.

Table 1 summarizes 6 mission profiles for the AV-8B developed by the McDonnell-Douglas Corporation (1978). Their intent was to create profiles which include all AV-8B mission roles. These profiles provide a succinct basis for deriving pilot mission tasks that require external visual reference and the general nature of the visual environments in which these tasks are performed.

The mission scenarios have a continuity based on support of a Marine amphibious assault, inland exploitation and consolidation. The AV-8B assault support scenarios begin with LHA based operations followed by field site and finally improved site operations with a variety of weather, navigational and attack conditions. These scenarios were used for development of the potential task and visual requirements for Type-B V/STOL mission oriented training in a simulator.

The principal feature of the information in Table 1 is that V/STOL attack aircraft missions are distinguished from CTOL aircraft missions only because of the differences in takeoff and landing techniques. For all other phases of the mission V/STOL aircraft will operate in the same manner as CTOL aircraft.

Training Analysis

The training analysis is based on the current USMC Training and Readiness (T&R) pilot training syllabus (USMC, 1978) used by the AV-8A training squadron, VMAT-203, at the Marine Corps Air Station, Cherry Point,N.C.

The training analysis shows the amount and type of V/STOL flight training given to Marine pilots and indicates the type of training maneuvers that may be appropriate for fundamental training on a V/STOL simulator equipped with a visual system. This analysis defines the flight situations and environmental contexts in which training and operations occur.

Table 2 presents the general characteristics of the AV-8A pilot training syllabus. The course of instruction is based on successive achievement of degrees of combat readiness as indicated. Pilot training is divided roughly equally in time and sorties between training squadron instruction and unit squadron instruction. As expected, the training squadron instruction emphasizes basic aircraft operation and flight control while unit squadron instruction emphasizes mission related training.

TABLE 1. REPRESENTATIVE AV/8B MISSION PROFILES (McDonnell-Douglas Corp., 1978)

MISSION/SYLLABUS ELEMENTS	ALTITUDE (MIN/MAX)	AIRSPEED (MIN/MAX)	TYPES LANDING	TYPES OF TAKEOFF	VISIBILITY REQMNT	SIGNIFICANT VISUAL CHARACTERISTICS
INTERDICTION (Strike I)	495 - Min 20,000 - Max	300 KIAS - Min 450 KIAS - Max	VL	STO	3-4 Miles Haze	. POL Depot . LHA . Marshall at 10 NM
CLOSE AIR SUPPORT (Strike II)	290 - Min 15,000 - Max	300 KIAS - Min 450 KIAS - Max	VL	STO	8 Miles Light Rain	. Fortified Positions . LHA
CLOSE AIR SUPPORT (Strike III)	300 - Min 1,500 - Max	360 - Max	VL	STO (Less than 700')	Unlimited Then Rain Showers	. Forward Base . AWLS Intercept at 5 NM . Glideslope inter-cept at 3 NM . Troop Concentration
INTERDICTION (Strike IV)	200 - Min 1,500 - Max	300 - Min 480 - Max	VL	STO	7 Miles, Scattered	. Truck Park . Forward Base
CLOSE AIR SUPPORT (Strike V)	< 100 - Min 3,500 -(apex of pop up)	420 - Max	VL	VTO	3,000 Scattered 8,000 Overcast, 2-3 Miles	. Forward Site (Pad) . Tanks
INTERDICTION (Strike VI)	100 - Min 1,500 - Max	360 - Min 450 - Max	SL	STO	10,000 ft Scattered, 7 Miles	. Forward Site (Road) . Armored Personnel Carriers . Forward Base . 1 Aggressor Aircraft

TABLE 2. GENERAL CHARACTERISTICS OF AV-8A PILOT TRAINING SYLLABUS

Level of Proficiency		Length	Where Given	No. of Sorties
Combat Capable	(60%)	28 weeks	Training Squadron	74
Combat Ready	(10%)	13 weeks	Squadron	39
Combat Qualified	(15%)	9 weeks	Squadron	28
Fully Combat Qualified	(15%)	10 weeks	Squadron	38
	100%	60 weeks		179

Table 3 shows the V/STOL-unique activities that are required during the 74 sorties flown in the tranining squadron phase of training. As shown in Table 2, 179 sorties are required for full combat qualification in the AV-8A. There are 62 sorties (35% of the 179 total sorties) in the training squadron phase that explicitly require one or more V/STOL activities. The remaining 117 (65%) sorties are not specifically intended to train V/STOL-unique phases of flight, rather they are intended to train aspects of the AV-8A mission which are accomplished during aerodynamic flight. Syllabus descriptions of these sorties do not indicate which, if any, of the V/STOL-unique flight phases are incorporated in these sorties; however, discussions with training squadron personnel and examination of mission analysis documentation indicate that these V/STOL phases of flight are routinely incorporated into these sorties.

Fifty-nine (59) of the 62 sorties identified above require the pilot under instruction to become familiar with, and to correctly use, visual cues external to the cockpit in the execution of the V/STOL-unique phases of flight. The three exceptions are those sorties in the instrument portion of the syllabus. These are all flown under the hood.

Tables 1 and 4 summarize the analyses of the mission and training activities and show the applicable V/STOL maneuvers employed, i.e., type of takeoff and landing, contextual factors, including minimum and maximum altitude and airspeed, and salient visual characteristics when given.

Accident Information

Accident information for V/STOL aircraft was available from three sources. The first two sources were published analysis reports (Enders and Thurman, 1970; Leng, 1976). The third source was the Navy Safety Center, Norfolk, Va., which provided the Contracting Officer's Technical Representative (COTR) data on AV-8A accidents which occurred up to September 1978 and were attributable wholly or in part to human error.

TABLE 3. V/STOL UNIQUE MANEUVERS BY SORTIE REQUIRED DURING TRAINING THAT RELY ON EXTERNAL VISUAL INFORMATION

TRAINING SORTIE	VERTICAL TAKEOFF	ACCEL. TRANS.	DECEL. TRANS.	SLOW LANDING	ROLLING VERTICAL LANDING	VERTICAL LANDING	VIFF	HOVER
Helicopter Famlrzation (4)								
.HFAM 1	x	x	x			x		x
.HFAM 2	x	x	x			x		x
.HFAM 3	x	x	x			x		x
.HFAM 4	x	x	x			x		x
Famlrzation (21)								
.FAM 1				x				
.FAM 2				x				
.FAM 3				x				
.FAM 4				x				
.FAM 5	x (RVTO)				x			
.FAM 6	x (RVTO)		x		x			
.FAM 7	x (RVTO)				x			
.FAM 8	x	x	x	x		x		x
.FAM 9	x	x	x			x		x
.FAM 10	x	x	x	x		x		x
.FAM 11	x	x	x	x		x		x
.FAM 12	x	x	x			x		x
.FAM 13	x	x	x	x	x	x		x
.FAM 14	x	x	x			x		x
.FAM 15	x	x	x	x		x		x
.FAM 16	x	x	x	x		x		x
.FAM 17	x	x	x			x		x
.FAM 18	x	x	x	x		x		x
.FAM 19	x (RVTO)	x	x		x	x		x
.FAM 20	x (RVTO)	x	x	x	x	x		x
.FAM 21	x	x	x	x	x	x		x
Instrument (4)								
.INST. 2				x	x			
.INST. 3					x			
.INST. 4	x			x	x	x		x
Formation (3)								
.FORM 1				x			x	
.FORM 2				x				
Night FAM (3)								
.Night 1	x	x	x	x	x	x		x
.Night 2	x	x	x	x	x	x		x
.Night 3				x	x			
Visual Navigation (4)								
.NAV 1-4	-	-	-	-	-	-	-	-
V/STOL Consolidation (7)								
.VCON 1	x				x			x
.VCON 2-3	x				x			x
.VCON 4-5	x	x	x	x	x	x		x
.VCON 6	x	x	x			x		x
.VCON 7	-	-	-	-	-	-	-	-
Confined Area Landings (3)								
.CAL 1	x	x	x			x		x
.CAL 2	x	x	x			x		x
.CAL 3	x	x	x			x		x

TABLE 3. V/STOL UNIQUE MANEUVERS BY SORTIE REQUIRED DURING TRAINING THAT RELY ON EXTERNAL VISUAL INFORMATION (continued)

TRAINING SORTIE	VERTICAL TAKEOFF	ACCEL. TRANS.	DECEL. TRANS.	SLOW LANDING	ROLLING VERTICAL LANDING	VERTICAL LANDING	VIFF	HOVER
Basic Tactics (5)								
.BTAC-2							x	
.BTAC-3							x	
.BTAC-4							x	
.BTAC-5							x	
Field Carrier Landing Prac. (4)								
.FCLP-1			x			x		x
.FCLP-2			x			x		x
.FCLP-3			x			x		x
.FCLP-4			x	x		x		x
Adv. FCLP (10)								
.ADFCLP-1			x			x		x
.ADFCLP-2	x	x	x			x		x
.ADFCLP-3			x			x		x
.ADFCLP-4-9	x	x	x			x		x
.ADFCLP-10	x	x	x			x		x
Carrier Qual. (10)								
.CQ-1			x			x		x
.CQ-2			x			x		x
.CQ-3	x	x	x			x		x
.CQ-4	x	x	x			x		x
.CQ-5	x	x	x			x		x
.CQ-6	x	x	x			x		x
.CQ-7 (Night)			x			x		x
.CQ-8 (Night)	x	x	x			x		x
.CQ-9 (Night)	x	x	x			x		x
.CQ-10 (Night)	x	x	x			x		x
Column Totals:	41	35	45	22	16	45	5	47

TABLE 4. V/STOL UNIQUE MANEUVERS BY TRAINING PHASE

MISSION/SYLLABUS ELEMENTS	ALTITUDE (MIN/MAX)	AIRSPEED (MIN/MAX)	TYPES LANDING	TYPES OF TAKEOFF	VISIBILITY REQMNT	SIGNIFICANT VISUAL CHARACTERISTICS
1. Familiarization	N/G	N/G	CL SL RVL VL	CTO RVTO VTO	N/G	Runway width=150' min. Runway length=8000' min.
2. Instrument	. 300 AGL min. . Max. N/G	N/G	RVL SL VL	STO VTO	W/Hood	
3. Formation	. 5000 min. . 15000 max.	N/G	SL RVL VL	STO CTO VTO	N/G	Simulated 72' square pad
4. Night FAM	N/G	N/G	SL RVL VL	CTO STO VTO	Night	. Lighted runway . Mirror or FLOLS
5. Visual Navigation	. Min= . 1000=Max.	360-540 Kts.	N/G	N/G	VMC	Visual checkpoints
6. V/STOL Consolidation	N/G	N/G	CTL SL VL RVL	CTO STO VTO RVTO	N/G	. Standard runway . 100' x 100' VTOL pad
7. Confined Area Landings	N/G	N/G	VL	STO VTO	N/G	. 96' x 96' Pad W 72' x 72' Markings
8. Basic Tactics	N/G	N/G	N/G	N/G	N/G	. 1 opposing A/C
9. FCLP	N/G	N/G	VL SL	STO	N/G	. Simulated carrier deck . 72' x 72' Area on deck . FLOLS . LSO . Port deceleration . Starboard translation
10. Adv. FCLP	N/G	N/G	VL	STO VTO	Night	. Simulated lighted carrier deck . LSO . FLOLS . Port deceleration . Starboard translation
11. Carrier Qual	N/G	N/G	VL RVL	STO VTO	Day & night	. Carrier deck . LPH deck . Port deceleration . Starboard translation

TABLE 5. R&D V/STOL ACCIDENTS WHICH OCCURRED IN THE U.S. UP TO 1970 (Enders and Thurman, 1970)

Phase of Flight	Number of Accidents	Attributed Cause	
Hover	8	Pilot Factor	6
Landing	8	Design	19
Transition	5	Operational	3
T.O.	3	Unknown	2
Ground	3		
Cruise	3		
Total:	30	Total:	30

TABLE 6. AV-8A ACCIDENTS 1971 - 1976 (Leng, 1976)

Phase of Flight	Number of Accidents
HVR	1
Vertical Take-Off	4
Accelerating Transition	1
Conventional Flight	6
Decelerating Transition	4
Slow Landing	1
Rolling Vertical Landing	1
Vertical Landing	2
Landing Roll	4
Total:	24

The first analysis reported a total of thirty V/STOL accidents which occurred in the United States up to 1970. The flight phases in which the accidents occurred and the attributed major causal factors are shown in Table 5. 63% of the accidents were attributed to design causes and 20% to pilot factors. This is not suprising since V/STOL aircraft were primarily undergoing research and development testing. The difficulty of piloting V/STOL aircraft in the thrust-borne phases of flight is suggested, however, by the fact that 80% of these accidents occurred in these phases.

The second analysis report (Leng, 1976) covered AV-8A accidents between the 1971 introduction of the AV-8A into service in the U.S. Marine Corps and November 1976. The total number of mishaps was 24. Of these 24, 15 were reported to involve pilot error. The flight phases in which the 24 mishaps occurred are shown in Table 6. Again it is apparent that a large percentage of the accidents occurred during the V/STOL-unique phases of flight. It is also worth noting that four out of the 24 accidents occurred during the landing roll.

Because of the sensitivity of accident data a current complete description of AV-8A accidents could not be obtained. The summary information provided by the COTR indicated that of all the AV-8A accidents which were wholly or partially atributed to human error, 25% occurred in the V/STOL-unique flight phases. A significant though substantially smaller number of accidents occurred during taxi or ground roll after landing. It should be recognized that most of the accidents covered in the summary data were also included in the analysis by Leng (1976).

It is apparent from the accident analyses that, from a safety standpoint, simulator training of V/STOL piloting tasks during the thrust-borne phases of flight would be highly desirable. The accident data also suggests that simulator training of ground movements, i.e., taxi and roll after landing would probably be worthwhile for safety reasons.

IMPLICATIONS FOR SIMULATOR TRAINING

The net result of the mission, training and accident analyses is that the V/STOL-unique phases of flight, i.e., takeoff, landing and the transitions between thrust-borne and wing-borne flight are most likely to be emphasized during training in future V/STOL simulators. Mission requirements for V/STOL aircraft do not differ from those for CTOL aircraft except where and how they takeoff and land. The training analysis revealed that a great deal of training time is devoted to the V/STOL-unique flight tasks. The accident analyses confirm that V/STOL aircraft place high workload demands on the pilot during thrust-borne phases of flight. Since 25% of the AV-8A mishaps occurred during thrust borne flight, the desireability of training V/STOL tasks in a simulator for safety reasons is evident.

There is at least one additional reason to expect that V/STOL simulator training will concentrate on the V/STOL-unique flight tasks. Fuel expenditures are greatest during fully or partially thrust-borne flight. Simulator training would conserve both fuel and time since the training of V/STOL tasks could proceed without the need for refueling and travel between the practice area and the refueling area.

Table 7 is a list of the V/STOL flight tasks which should be considered to be the primary task context for research on V/STOL simulator visual system requirements. Ground movements have also been included in the list because of the signifcant percentage of accidents which occurred during taxi and ground roll after landing. The conventional landing is also included as a V/STOL-unique flight task because of the relatively high landing speed (in excess of 140 knots) for the AV-8A and the fact that some accidents have occurred during the ground roll after a conventional landing.

TABLE 7. SUMMARY OF V/STOL-UNIQUE FLIGHT TASKS APPROPRIATE FOR INVESTIGATION OF V/STOL SIMULATOR VISUAL SYSTEM REQUIREMENTS

1. Hover
2. Hover movement
3. Vertical Takeoff
4. Rolling Vertical Takeoff
5. Short Takeoff
6. Accelerating Transition
7. Decelerating Transition
8. Vertical Landing
9. Rolling Vertical Landing
10. Slow Landing
11. Conventional Landing
12. Ground Movement (taxi and ground roll)

IMPLICATIONS FOR VISUAL SIMULATION

The V/STOL mission requirements are the reasons for development of V/STOL aircraft rather than vice-versa. Consequently, the mission requirements always involve V/STOL-

unique requirements. The main result of the analyses was the conclusion that the V/STOL-unique tasks are likely to be the primary tasks trained in future V/STOL simulators. The second result was establishing the general features of the environment in which V/STOL operations are likely to occur. These are of obvious relevance to the scene content requirements for a simulator used for V/STOL visual system research.

The last columns of Tables 1 and 4 indicate significant aspects of the visual environment in which operational V/STOL flights will be conducted. Navy V/STOL operations at sea will involve launch and recovery from both large carriers (CVs) and medium-sized ships such as LPHs and LHAs. Shore based operations will occur at conventional, improved airfields as well as at partially improved (planked landing pads and visual landing aids) forward sites. Terrain, vegetation and cultural features will naturally depend on the geographic area of operations. In any shore based setting it can be expected that V/STOL operations will involve low level flight and takeoff and landings in confined as well as open areas. Both day and night operations can be expected to occur, and present weather minimums of 400 feet ceiling and one mile visibililty are likely to be reduced, perhaps to 200 feet and one-quarter mile visibility, and eventually to zero ceiling and 700 feet visibility (Advanced Developments Projects Office, 1976, 1978) for both sea and shore V/STOL flight operations.

At sea, the principal features of the visual environment are the ship the aircraft is operating from, its lighting during night, possibly other ships, and the sea itself. The movements of the ship, the ship's wake and features of the sea may be important sources of information for the V/STOL pilot.

On land, the static features of the environment and visual landing aids at night probably provide all the required sources of visual information required by the pilot for V/STOL-unique flight tasks.

Obscuration (limitations of ceiling and visual range), is an important characteristic of the real world which affects flight task performance and is a feature that should be manipulatable in a V/STOL simulator visual system for research purposes. The main effects of obscuration from rain, snow, fog, haze and clouds is reduction of visibility by scattering and absorbtion of light. The net visual effect is a reduction of contrast which makes objects and areas invisible or only faintly visible. A homogeneous obscuration which increases in density as a function of distance, and for which the density gradient is adjustable, should fulfill all fuctional requirements for simulation of ceilings and reduced visibility.

Table 8 summarizes the general environmental features which should be included as part of the scene content presented by a V/STOL simulator visual system used for research purposes.

There is nothing particularly remarkable about these features; most of them would be included in any flight simulator used for training of Naval air operations at sea and over land. This set of features is simply the substantive starting point for considering what information a V/STOL pilot requires and how and to what degree this information is afforded by the representations presented in a simulated scene. Since V/STOL-unique flight tasks will occur at low speeds and low altitiudes, the way the features listed in Table 8 are represented will be fundamental to research on V/STOL visual system requirements.

TABLE 8. BASIC FEATURES OF V/STOL OPERATIONAL ENVIRONMENT RELEVANT TO SCENE CONTENT FOR V/STOL VISUAL SYSTEM RESEARCH

A At Sea Environment

1. Carrier (CV)
2. LHA
3. LPH
4. Ship lighting and Visual Landing Aids
5. Ship wake
6. Ship movements
7. Seas

B Shore Environment

1. Airfield, conventional runway (e.g., 150 x 8000 feet)
2. V/STOL pads, with and without markings
   a. 96 feet square
   b. 72 feet square
3. Lighting and Visual Landing Aids
4. Partially improved forward landing sites
5. Unimproved forward landing areas
   a. open
   b. confined
6. Terrain features
7. Vegetation
8. Cultural features

C Meteorological Environment

1. Day
2. Dusk
3. Night
4. Obscuration (variable density)

V/STOL PILOT TASK ANALYSIS AND VISUAL INFORMATION REQUIREMENTS

An analysis was conducted to explicate the tasks required for all V/STOL missions. The emphasis was on the V/STOL-unique phases of flight. The sources of the information contained in this analysis of V/STOL pilot tasks include the data acquired about AV-8A operations during a visit to VMAT-203, the U.S. Marine Corps AV-8A Training Squadron, USMC Air Station, Cherry Point, N.C., the NATOPS Manual for the AV-8A, and information acquired regarding past Type-A V/STOL concepts. This information was combined with available task analyses of helicopter operations and the experience of the analysts to produce the list of V/STOL tasks and associated sources of information, either inside or outside the cockpit.

Before describing the task analysis and the derived visual information requirements it will be useful to present what is meant by visual information and a working assumption about the relationship between V/STOL piloting tasks and information requirements.

Visual Information

In this report information is assumed to be defined by the purpose it serves. Information is not considered to be an entity nor is it considered to be a characteristic of the source of information. As applied to the visual perception of the world, information does not exist in the ground, the vegetation or other things in the scene. Things in the world only <u>afford</u> information, i.e., permit information to be acquired. Perception is the process by which information is acquired. Information, in effect, is the perceptual conclusion that occurs because it is relevant to something the pilot is doing or will do. The pilot does not normally see cues such as perspective relationships and then consciously work out their implications. As will be dicussed later in this report, it is possible for the pilot to adopt an analytic attitude and consider the scene as an image, but this is a special process. More usually, the pilot simply 'sees' the information of interest.

For example, during a landing approach, it is useful for a pilot to have some idea of his altitude. When he looks at the world through the windscreen of his aircraft he does not see that things look small or that the scene appears to flow slowly past him. The pilot perceives that he is high above the ground. He perceives altitude and not the abstract concepts of perspective geometry which are often evoked to explain why a pilot can, in fact, perceive altitude. Being able to understand and describe how perceptual processes work is a very useful thing but it is not a primary concern to the pilot during the time he is trying to land his aircraft. It is more accurate to say that the pilot perceives altitude information because that is what his information need is at the moment.

Throughout the remainder of this report a distinction will be made between information, the affordance of information and sources of information. Information will be used to mean the perceptual conclusions which occur because they are relevant to the pilot's task. The affordance of information will be used to mean that there are sources which permit relevant information to be acquired because they are compatible with the pilot's perceptual abilities. Sources of information will be used to mean the things in the world, their inter-relationships and their relationship to the pilot and his aircraft.

V/STOL Pilot Tasks and Information Requirements

It was mentioned earlier that because of the difficulty of the piloting tasks during the V/STOL-unique flight phases these tasks are standardized to the extent possible. There are different types of V/STOL takeoffs and landings but once the type is chosen the control procedures are essentially fixed. The experienced pilot has learned the procedures and control techniques which help alleviate the high work-load demands of V/STOL-unique tasks. He knows when to do what throughout the flight profile. The principal routine demand on the V/STOL pilot therefore is to recognize when important aircraft states or profile points have been reached and to take the appropriate, planned actions. The principal non-routine demand on the V/STOL pilot is to recognize when departures from the desired profile occur and to take the appropriate, corrective actions. The latter demand requires an assessment of what control actions are appropriate as well as their execution.

The pilot obtains the information necessary for planned and corrective control actions from his cockpit instruments and the view of the external scene. Since the pilot is always attempting to execute the standard set of procedures for the chosen type of V/STOL takeoff or landing profile his information requirements remain the same for all instances of the same type of profile regardless of the environment he is operating in. The primary variation relative to the pilot's information needs is not in what information is required but in the sources from which it is acquired. The visual environment may vary from sea to shore, from place to place, during day and night and in the presence of obscurations, but the information the pilot needs remains the same for a given profile.

V/STOL Pilot Task Analysis

The approach to this task analysis was to identify all phases of flight, and the V/STOL pilot functions associated with those phases of flight. Those phases of flight which did not contain V/STOL-unique functions or task requirements were not subjected to detailed analysis. Those phases of flight or functions which are critical or unique to V/STOL flight were broken down to the task level. These descriptions of the

pilot's performance were cross checked against the information in the NATOPS Manual for the AV-8A to insure the accuracy of the sequence of events and the actions taken. Visual information requirements for each function were identified and classified as coming from inside or outside the aircraft. The results of this analysis are shown in Table 9.

The general visual information requirements identified in Table 9 were abstracted and a generic list of visual information requirements compiled. In light of the previously discussed assumption that information requirements for particular tasks are always the same regardless of the task setting, it is appropriate to produce a generic list. While the meanings of most of the items in the list are obvious, definitions have been given in all instances. One characteristic of this list is that some of the visual information requirements are defined in more than one way depending on what the pilot functionally perceives. For example, ground speed is incorportated into two definitions, position rate and relative distance rate. The definition of the information requirement depends on its significance to the pilot. The list of generic visual information requirements is shown in Table 10.

The visual information requirements were cross-tabulated against the major segments of each V/STOL-unique flight phase to insure that the generic visual information requirements list was complete. The generic visual information requirements for each V/STOL-unique flight phase is shown in Table 11. It should be noted in passing that these requirements do not differ substantially from visual information requirements for conventional aircraft. This is obvious when the visual information requirements shown in Table 10 are further compacted as presented in Table 12. These greatly abstracted categories of pilot information requirements are applicable to any aircraft, CTOL, VTOL or V/STOL.

TABLE 9. VISUAL INFORMATION SOURCES FOR V/STOL TASKS

Phase of Flight	Function	Tasks	Source of Visual Info. Out	Source of Visual Info. In
Preflight	1. Exterior check	Task level detail not required for this project, as none of these tasks are V/STOL peculiar	x	
	2. Pilot interior check			x
	3. Co-pilot interior check			x
	4. Start engines			x
	5. Perform engine run-up			x
	6. Perform system checks			x
	7. Departure clearance comm.	N/R	-	-
	8. Complete pre-taxi check	1. Check instruments 2. Check, external		x
	9. Taxi ACFT.	1. Release brakes	x	
		2. Increase power	x	
		3. Engage nosewheel steering to control ACFT. direction	x	
		4. Use Brakes/ throttle to control ACFT. speed	x	
	10. Check flight controls	N/R	x	x
	11. Check flight instruments	N/R		x
	12. Check engine instruments	N/R		x
	13. Monitor/ground airspace for takeoff	1. Monitor ground traffic	x	
		2. Monitor air traffic	x	

TABLE 9. VISUAL INFORMATION SOURCES FOR V/STOL TASKS (cont'd)

Phase of Flight	Function	Tasks	Source of Visual Info. Out	In
Takeoff (STO & VTO)	1. Ground roll	1. Set trim		x
		2. Adjust power for takeoff		x
		3. Check RPM		x
		4. Check/adjust nozzle/thrustor position		x
		5. Set flaps		x
		6. Engage nosewheel steering		x
		7. Monitor airspace/ runway	x	
		8. Release brakes		x
		9. Monitor heading	x	
	2. Liftoff	1. Monitor RPM		x
		2. Monitor heading	x	
		3. Monitor altitude	x	
		4. Monitor airspeed		x
		5. Monitor AOA	x	x
		6. Adjust nozzles/ thrustors		x
		7. Monitor sideslip	x	
	3. Accelerating transition	1. Set full power		x
		2. Maintain attitude constant		x
		3. Landing gear up		x
		4. Flaps up		x
		5. Nozzles/thrustors full flaps		x
Takeoff (VTO & RVTO)	1. Ground activity	1. Set trim		x
		2. Set flaps		x
		3. Set brakes on		x
		4. Engage nosewheel steering (RVTO)		x
		5. Monitor airspace/ runway	x	
		6. Adjust nozzles/ thrustors		x
		7. Adjust/monitor power		x
		8. Release brakes (RVTO)		x
		9. Monitor heading and power	x	
		10. Adjust nozzles/ thrustors (RVTO)		x

TABLE 9. VISUAL INFORMATION SOURCES FOR V/STOL TASKS (cont'd)

Phase of Flight	Function	Tasks	Source of Visual Info. Out	In
Takeoff (VTO & RVTO) (cont'd)	2. Lift off	1. Monitor/control heading	x	
		2. Monitor/control attitude	x	
		3. Adjust power		x
		4. Adjust nozzles/ thrustors for forward flight	x	x
		5. Monitor sideslip	x	
	3. Accelerating transition	(same as CTO/STO)		
Enroute	1. Normal cruise	Task level detail not required for this project as none of these tasks are V/STOL peculiar		x
	2. Communications			x
	3. Monitor instruments			x
	4. Monitor air-space		x	
	5. Monitor/adjust altitude		x	x
	6. Monitor/adjust heading		x	x
	7. Interpret terrain		x	
	8. Determine position		x	x
	9. Crew coordination			x
Mission	1. Maneuver	1. Navigate a course selected to IP	x	x
		2. Monitor airspace	x	
		3. Communicate (supported unit, FAC, etc.)		x
		4. Revise/modify flight path as required	x	x
	2. Arrive at IP	1. Verify position	x	x
		2. Activate weapon sensor systems		x
		3. Communicate		x
		4. Receive target data	x	x

TABLE 9. VISUAL INFORMATION SOURCES FOR V/STOL TASKS (cont'd)

Phase of Flight	Function	Tasks	Source of Visual Info. Out	In
Utility Configuration	3. Land aircraft (ashore)			
	3.A CL	1. Executive VFR recovery and landing	x	x
	3.B SL	1.A Execuite Tacan recovery and landing	x	x
		1.B Execute precision recovery and landing	x	x
Mission	3.C RVL 3.D VL	See recovery phase for task level detail		
Utility Configuration	4. Land aircraft (aboard ship) 4.A RVL 4.B VL	See recovery phase for task level detail		
	5. Perform takeoff 5.A CTO 5.B STO 5.C RVTO 5.D VTO	See departure function 9 for task level detail		
ASW/AEW Configuration	6. Engage targets	1. Acquire target(s)	x	x
		2. Attack target(s)	x	x
		3. Receive enemy detection	x	x
		4. Receive hit/ assess damage	x	x
		5. Execute evasive maneuvers	x	x
Recovery-Shore (CL & SL)	1. At 180° position	1. Complete landing checklist		x
		2. Set nozzles/ thrustors		x
		3. Monitor/adjust AOA		x
		4. Adjust heading	x	x
	2. At 45° position	1. Adjust nozzles/ thrustors (SL)	x	

TABLE 9. VISUAL INFORMATION SOURCES FOR V/STOL TASKS (cont'd)

Phase of Flight	Function	Tasks	Source of Visual Info. Out	In
Recovery-Shore (CL & SL) (cont'd)	3. On final	2. Increase power (SL)		x
		3. Control AOA and descent with nozzles/throttle/stick	x	x
		4. Adjust heading	x	x
	4. Touchdown	1. Power to idle		x
		2. Adjust nozzles/thrustors for braking		x x
		3. Engage nosewheel steering		x
		4. Adjust trim	x	x
		5. Apply brakes	x	x
Recovery RVL & VL	1. Approaching key	1. Complete landing checklist		x
		2. Adjust nozzles/thrustors		x
		3. Adjust AOA		x
		4. Observe GSI (ship)	x	
		5. Adjust power		x
	2. At key	1. Verify position	x	x
		2. Lower gear		x
		3. Set nozzles/thrustors for hover		x
		4. Adjust power to control rate of descent	x	x
		5. Monitor/adjust attitude	x	x
		6. Monitor/control sideslip	x	
		7. Receive LSO call (ship)		x
	3. Hover	1. Establish/maintain hover altitude by adjusting power	x	x
		2. Establish/maintain position	x	
		3. Monitor RPM		x
		4. Monitor EGT		x
		5. Receive LSO call (ship)		x

TABLE 9. VISUAL INFORMATION SOURCES FOR V/STOL TASKS (cont'd)

Phase of Flight	Function	Tasks	Source of Visual Info. Out	In
Recovery RVL & VL	4. Landing	1. Check brakes off		x
		2. Adjust power to begin descent	x	x
		3. Monitor ground/ deck references	x	
		4. Maintain heading	x	x
		5. Maintain attitude	x	x
		6. Maintain positive rate of descent	x	x
		7. Adjust nozzles/ thrustors for RVL		x
	5. Touchdown	1. Set power to idle		x
		2. Set nozzles/ thrustors for braking (RVL)		x
		3. Engage nosewheel steering (RVL)		x
		4. Set brakes		x
		5. Set nozzles/ thrustors for taxi		x
		6. Set trim		x
Postflight	1. Aircraft shutdown	Task level detail not required for this project, as none of these tasks are V/STOL peculiar		x
	2. Aircraft post flight checks			x
Contingencies/ Emergencies	1. Recover from spatial dis-orientation (lost)	Task level detail not required for this project, as none of these tasks are V/STOL peculiar		
	2. Missed approach			
	3. Engine failure			
	4. Engine over-heat			
	5. Aircraft fire			
	6. Compressor stall/power surge			
	7. Hydraulic system failure			
	8. Electrical system failure			

TABLE 10. GENERIC VISUAL INFORMATION REQUIREMENTS FOR V/STOL AIRCRAFT

1. Pitch - The angle of the longitudinal axis of the aircraft with respect to the horizon.
2. Pitch rate - The rate of change of pitch.
3. Roll - The angle of the lateral axis of the aircraft with respect to the horizon.
4. Roll rate - The rate of change of roll.
5. Yaw - The angle of the longitudinal axis of the aircraft on the horizontal plane of the aircraft with respect to the direction of motion or initial heading during hover.
6. Yaw rate - The rate of change of yaw.
7. Altitude - The height of the aircraft above the ground.
8. Altitude rate - The rate of change of altitude.
9. Position, side to side - The horizontal distance between the aircraft and a specific ground point.
10. Position rate, side to side - The rate of change of position side to side.
11. Position, fore-aft - The longitudinal distance between the aircraft and a specific ground point.
12. Position rate, fore-aft - The rate of change of position fore-aft. Also means ground speed.
13. Relative heading - The angle of the direction of travel of the aircraft in the horizontal plane with respect to a line between the aircraft and a specific ground point.
14. Relative heading rate - The rate of change of relative heading.
15. Relative distance - The distance between the aircraft and a specific ground point along the general line of travel.
16. Relative distance rate - The rate of change of relative distance, the closure or opening rate.
17. Detection of object(s) - The ability to sense the presence of an object or objects. Detection implies sensing of the angular direction of the object with respect to the aircraft but not recognition, distance, orientation, position or movement.
18. Recognition of object(s) - Determination of what an object is. Implies detection.
19. Orientation of object(s) - Determination of the relative aspect of an object. Applies most often to other aircraft and ships. Implies detection.
20. Position of object(s) - Determination of relative spatial relationship between object and other objects.
21. Movement of object(s) - Determination of movement characteristics of object independent of relative motion between aircraft and object.

TABLE 11. GENERIC VISUAL INFORMATION REQUIREMENTS FOR V/STOL UNIQUE TASKS

INFORMATION REQUIREMENTS / TASKS	Pitch	Pitch Rate	Roll	Roll Rate	Yaw	Yaw Rate	Altitude	Altitude Rate	Position Side to Side	Position Rate Side to Side	Position Fore-Aft	Position Rate Fore-Aft	Relative Heading	Relative Heading Rate	Relative Distance	Relative Distance Rate	Detection of Object(s)	Recognition of Object(s)	Orientation of Object(s)	Position of Object(s)	Movement of Object(s)
Phase of Flight - Pre-Flight																					
Functions:																					
Pre-taxi checks									X		X		X				X			X	X
Taxi aircraft									X		X	X			X	X	X			X	X
Check ground/airspace clearance															X		X			X	X
Phase of Flight - Takeoff																					
Functions:																					
Conventional Takeoff																					
ground roll									X	X		X			X		X			X	X
lift-off	X	X	X	X	X	X		X		X		X	X	X	X		X			X	X
Short Takeoff																					
ground roll									X	X		X			X		X			X	X
lift-off	X	X	X	X	X	X		X		X		X	X	X	X	X	X				
Rolling Vertical Takeoff																					
ground roll												X	X	X	X	X				X	X
lift-off																					
accelerating transition	X	X	X	X	X	X		X		X		X	X				X			X	X
Vertical Takeoff																					
hover	X	X	X	X	X	X	X		X	X	X	X	X	X							
accelerating transition	X	X	X	X	X	X		X		X		X	X				X			X	X
Phase of Flight - Landing																					
Functions:																					
Conventional Landing																					
180 degree position	X	X	X	X	X	X	X	X	X	X	X	X	X			X		X	X	X	X
45 degree position	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X
touchdown	X		X		X				X		X		X	X	X	X				X	X
ground roll									X		X	X			X	X	X			X	X
Slow Landing																					
key	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
decelerating transition	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
touchdown	X		X		X				X	X	X		X	X	X	X				X	X
ground roll									X		X	X			X	X	X			X	X
Rolling Vertical Landing																					
key	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
decelerating transition	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
touchdown	X		X		X				X	X	X	X			X	X	X	X	X	X	X
ground roll									X		X	X			X	X	X				
Vertical Landing																					
key	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
decelerating transition	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
hover	X	X	X	X	X	X	X	X	X	X	X	X									
touchdown									X	X	X	X									

TABLE 12. HIGHLY ABSTRACTED SUMMARY OF PILOT INFORMATION REQUIREMENTS

1. ATTITUDE
    - Bank Angle
    - Roll Rate
    - Yaw
    - Yaw Rate
    - Pitch
    - Pitch Rate

2. POSITION
    - Current (Absolute)
        - Horizontal
        - Altitude
    - Future (Relative)
        - Direction
        - Distance
    - Rates
        - Ground Speed
        - Vertical Speed
        - Heading

3. RECOGNITION
    - Places
    - Objects
    - Events

After reading this section and looking at the visual information requirements listed in Tables 10, 11 and 12, the reader could reasonably expect the analysis to continue with descriptions of how this information is afforded to the pilot by sources in the world, what perceptual abilities the pilot uses to acquire the necessary information and his sensitivities to the afforded information. Unfortunately, this is not possible. A number of previous studies have developed lists of visual information requirements, and/or hypothesized what visual cues a pilot uses to perform his tasks (Carel, 1961, 1965; Havron 1962; Matheny et al 1971; AGARD, 1972; Stark, 1977; Quanta Systems, 1979). Eventually they arrive at essentially the same conclusion, i.e., there is no logical, systematic way of proceeding from visual information requirements to the nature of the sources required to afford the information to the pilot. There is a large gap in the knowledge of visual perception, human information processing and how to characterize visual scenes in terms of affordance of information to pilots.

The same gap has been encountered before. Carel(1965) had the task of determining the requirements for a pictorial contact analog display instrument. After examining several lists of pilot information requirements that had been developed in previous studies he conluded:

> "The output of most studies of pilot information requirements is not a total description of pilot information requirements but is a list of information presented by current or proposed instruments or a selection of those parameters that should be displayed in the cockpit for a given system according to the judgments of the investigator.
>
> "One may conclude that lists of pilot information requirements are almost useless as a basis for deciding what information to include in pictorial displays for the pilot. Furthermore it can be argued that even if the information requirements for the pilot were exhaustively known and the required performance for each displayed variable specified numerically, a creative leap is still required to vault the gap between those requirements and the best way of encoding the information. There is no logical or necessary connection between these lists of information requirements and methods of encoding the information." (Carel, 1965)

The visual information requirements developed in this section will contribute little, in themselves, to determining what must be portrayed by the visual system of a V/STOL simulator. Their primary value will be apparent when the visual system research issues and recommended research statements are described later in this report. The research issues are basically hypotheses about how visual information is afforded and acquired. The visual information requirements set the scope of the subject matter for the research issues. The object of the recommmended research is to determine how information should be afforded by a simulator visual system to meet these requirements.

The visual information requirements are surely afforded in the natural world, but the issues are, what are the essential information affordance characteristics of the natural visual environment that must be present in a simulated scene and how should the sources of information be represented? The remainder of this report addresses these issues. The next section presents some ideas about flight training and flying behavior. The second following section discusses some relevant features of visual perception. After these background sections the research issues themselves are formulated and discussed. The report concludes with the functional requirements for a V/STOL research simulator visual system.

SECTION III

SIMULATOR REQUIREMENTS, FLYING BEHAVIOR AND FLIGHT TRAINING

SIMULATOR REQUIREMENTS

To produce statements of the required research, implies that something is known about the general nature of specifying simulator visual system requirements. In fact, how visual system requirements should be stated is uncertain. There are two related ways of specifying these requirements. The first is to specify the functional requirements in terms of what the visual system must do to support the training requirements. The second is to specify the engineering requirements, i.e., physical characteristics of the visual system equipment. Ideally, the engineering requirements would be developed as a consequence of the functional requirements. In practice, however, engineering requirements are usually developed with very minimal information about the functional requirements. Functional requirements for simulator visual systems are very difficult to state. Why this is so will be discussed to provide background for understanding how the research issue topics, discussed in a later section, were developed.

Flight Simulator Components

The principal functional components of a full-mission flight simulator are the cockpit controls, the cockpit instruments, the motion system (platform and/or G seat), the aural system (radio communications and sounds), the visual system and the controlling computer system hardware and software (including a model of aircraft behavior). All of these components serve one purpose, to create an environment similar to that of an aircraft in flight. The simulated environment can be regarded as consisting of two components, the immediate environment within the cockpit and the external environment, i.e., the world.

Cockpit Environment

When the pilot is in the cockpit of a flight simulator the immediate environment he experiences is the sights, sounds and feel of the cockpit instruments, controls and movements. These experiences in the cockpit depend only in a very limited way on the world environment in which the simulated aircraft is operating. The only external world factors that impact on the cockpit environment are air mass and electronic effects. That is, what happens in the cockpit depends on aerodynamic, wind and turbulence forces of the air acting on the aircraft and electronic emissions such as radio signals, radar returns and signals from other sensors.

The pilot's sensing of air effects is through aircraft movements, control feel and instrument readings. All electronic contact is through the appropriate aircraft receivers and the immediate sources of information acquired by the pilot are from either an aural display (sound) or a visual display instrument. Thus, within the cockpit, the pilot's contact with the outside world is limited to air and electronic effects and these are experienced only indirectly, through the aircraft and cockpit equipment.

The functional requirements to achieve simulation of the cockpit environment are relatively easy to state because of the restricted nature of the cockpit environment and the limited interactions with the world. Achieving these requirements is usually a straightforward engineering effort well within the state of the art. For the cockpit equipment all that is required is duplication of what exists in the cockpit of the aircraft being simulated. Simulation of the air and electronic characteristics also are relatively easy to achieve because only the effects must be simulated; not the environmental sources themselves. It is not necessary to model the atmosphere over a large area nor to model radio transmitters and radar targets. It is only necessary to model the effects on the aircraft or on the cockpit instruments to place the pilot in simulated contact with the outside world. All the environmental effects within the cockpit can be accomplished in a highly realisitic manner. There is no technical necessity (with the possible exception of motion effects) to restrict the realism of the cockpit environment.

External Visual Environment

For out-of-cockpit vision, there is no mediation between the pilot and the world. The light emitted or reflected from objects in the world places the pilot directly in contact with the world, and the visual world has virtually infinite complexity. For other environmental effects it is possible to begin simulation at the point where effects are mediated by the aircraft and its systems. Unlike these other environmental effects, there is no mediation between the world and the pilot's eyes where simulation of effects can be applied. To produce a realistic visual simulation of the world requires either modeling of the world itself or of the optic array of the world. Simulation of the aircraft environment and the effects of non-visual contacts with the outside world is one thing. Simulation of the visual world itself is quite another.

Limitations of Visual Simulation

It is recognized that visual systems, in one way or another, are technically limited in their ability to provide the pilot with the comprehensive, realistic view of the world he experiences in the cockpit of a real aircraft. It is also recognized that, within the technological limitations,

trade-offs are possible; that is, it is possible to produce some characteristics of the visual environment realistically at the expense of others.

For example, a camera-model based visual system can provide a detailed and realistic appearing scene of a terrain area at the expense of having a restricted gaming area (the geographic size of the terrain represented), a restricted field of view, lack of complex ground-object movements, and lack of flexibility to change the represented area. Computer generated image (CIG) based visual systems, on the other hand, can portray a much larger gaming area with a full field of view, can include complex ground-object movements and have great flexibility for changing the represented area. CIG systems, however, are limited in the amount of detail they can portray. Consequently, the scenes are very stark and cartoonish in appearance.

In summary, functional requirements for simulator visual systems, those assumed to be necessary for training, are very different from requirements for other components of a simulator which make up the pilot's simulated environment. The focus of the visual system requirements, unlike the functional requirements for other simulator components, must necesarily shift from the effects on the pilot, mediated by the aircraft, to the effects on the pilot of the world itself. Visual <u>information</u> requirements, such as those developed in the previous section, are pilot referenced. Visual <u>system</u> requirements, however, must be information source, i.e., world, referenced. Because of the technical impossibility of realistically simulating all aspects of the visual environment, formulation of statements of functional visual system requirements must necessarily involve trade-off decisions about what features will be included or emphasized and what features will be omitted or not emphasized.

The importance of the fact that visual system requirements must address simulation of the world environment and not the limited and tractable environment of the cockpit is probably not fully appreciated by those people concerned with stating the objectives of flight training in a simulator. Consequently, they also do not appreciate the importance of the trade-off decisions which are inherent in statements of simulator visual system functional requirements. The apparent reasons for this lack of appreciation will be stated after some discussion of flying behavior and flight training which will provide some useful background for understanding these reasons.

ANALYSIS OF FLIGHT BEHAVIOR

There are two harmonious ways of conceptualizing a pilot's tasks. The first definitive analysis of flight behavior was developed in a 1947 by Alexander C. Williams, Jr. (reprinted in Roscoe, 1979). Williams conceived of flying as a global goal

directed behavior and the tasks of flying as sub-goals. More recent approaches to analyzing flight behavior incorporate this basic idea into a framework where the pilot's tasks are described as components of a multi-loop control system with the pilot serving as the controller (McRuer, et al, 1965; Carel, 1965; Roscoe, 1974, 1979; Jensen, 1979). Williams' model concentrates on the logical derivation and description of the types and sources of information required to support accomplishement of the sub-goal tasks. The control model emphasizes the differences in the time related characteristics of the control loops and the differentiations and integrations of information necessary to support the control activities.

Flying as Goal Directed Behavior

The initial and key assertion of Williams' original analysis of flight behavior is that out of a continuous complex stream of behavior any particular sequence can be considered as a unit if it is directed toward a given goal. Flying behavior is purposeful with a goal in mind. The overall goal, whether it is to fly and land at some airport or to accomplish some mission, can be subdivided into a chain of sub-goals. Events which occur during flight become meaningful when referenced to the goal to be accomplished. To achieve a goal the pilot must make a series of discriminations among courses of action open to him, select those that will lead him to the goal, and translate these courses of action into aircraft performance through the manipulation of controls.

Williams defines four sub-goals that are generically applicable to any flight task and five sources of information that are required to achieve these sub-goals. Williams' own words express it best:

> "First of all, let us attend to the process of discrimination. What courses of action are open to a pilot? He can do many things, but we suggest that (1) since his goal is always related to him directionally, he is obliged to make a directional discrimination; (2) since his goal is always related to him via the air, he must make a height or altitude discrimination; (3) since his goal is always related to him in time, he must make a temporal discrimination; (4) since his goal is always related to him via the continuing performance of his aircraft, he must make a mechanical discrimination. These discriminations, or course-of-action selections, we shall designate as sub-goals, or indices of desired performance.
>
> "We will contend that these four sub-goals are both necessary and sufficient for achieving any flight goal. Necessary means that in order to achieve a goal, each discrimination must be made; sufficient

means that no additional discriminations are required when these are made correctly. In other words, a pilot can achieve any flight goal provided he flies in the proper direction at the proper altitude for the proper time and with a properly functioning aircraft.

> "The question arises now concerning what information a pilot needs in order to set up these sub-goals, SGs, for his particular flight. Analysis suggests that there are only five independent sources of information pertinent to flight and that all other information a pilot may receive is important only because it stems from one of these five sources. They are: (1) the earth, (2) the air, (3) the aircraft, (4) the pilot, (5) other aircraft. In the process of discrimination, what the pilot does is to consider each of these five variables in the light of his goal or mission. This leads him to specific conclusions as to what each sub-goal must be in order to make a successful flight." (Williams, in Roscoe, 1979).

Williams goes on to justify why the four general sub-goals and five sources of information are sufficient for any flight task. He then says that once the sub-goals are set up they must be translated into aircraft performance by decisions concerning control movement and finally, actual manipulation of the controls. Again, quoting Williams,

> "Although the pilot does not normally make these [control manipulation] decisions consciously, each must be made implicitly, and for each the pilot must receive appropriate information: 1. When to move the controls. 2. Which control or controls to move. 3. In which direction to make the movements. 4. How much to move (in the sense of how large a movement pattern to make). 5. How long to move (in the sense of how long to continue the effect of a movement pattern)." (Williams, in Roscoe, 1979)

Flying Considered as Closed Loop Control Behavior

The system control model of flight tasks is illustrated in Figure 3. The left half of the figure shows the sub-goals which the pilot is attempting to accomplish and the right half of the figure shows the types of information the pilot uses to assess whether he is attaining his sub-goals or not and to make corrections as necessary. The time characteristics of the control processes are shown in a nested fashion. The tempo of sub-goal change and the acquiring of the necessary information is most rapid in the innermost loop and slowest in the outermost loop.

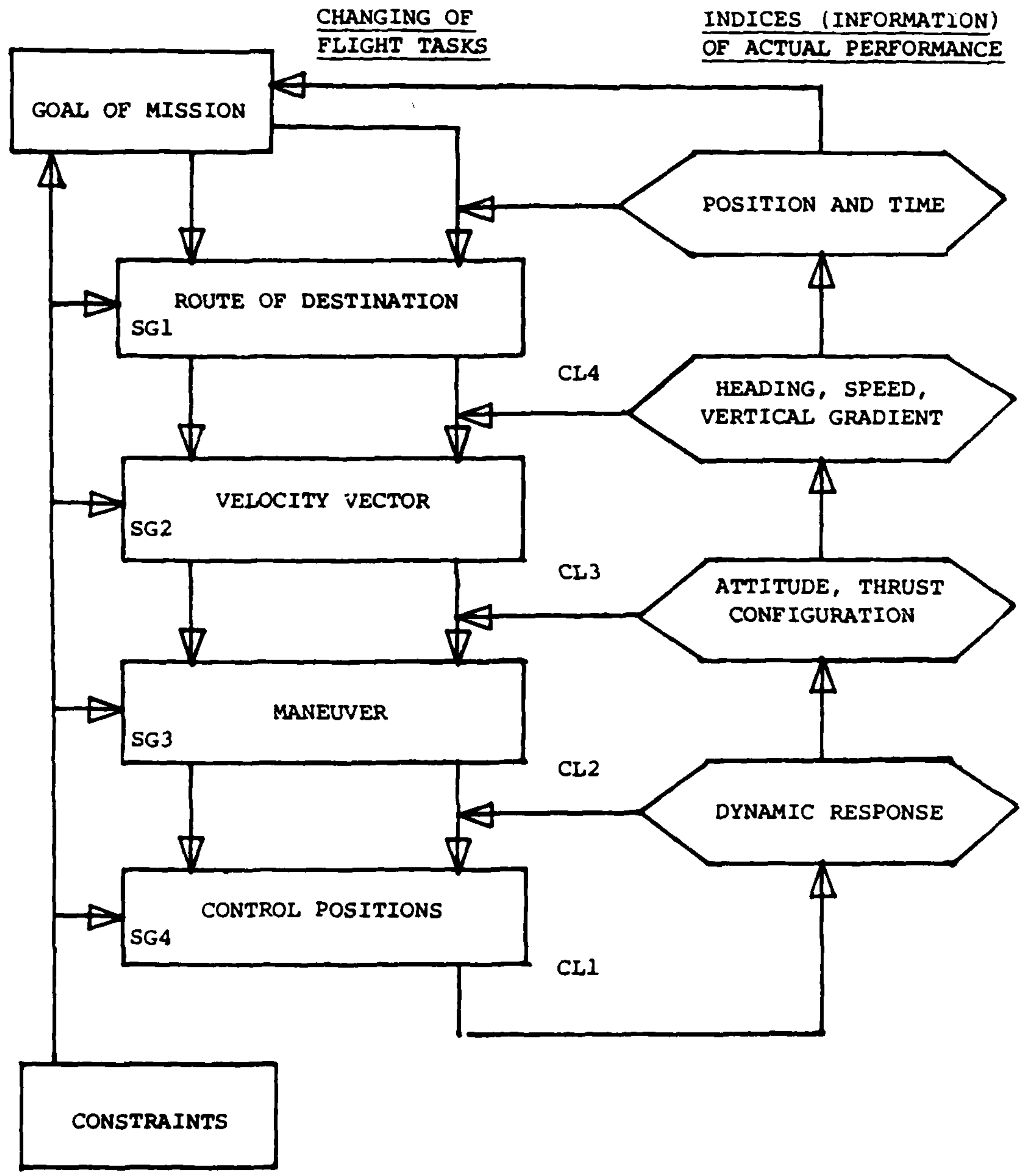

Figure 3. Control model of flying behavior emphasizing hierarchy of sub-goals and time dependent relationships between control actions and eventual effect on different indices of performance. (after Roscoe, 1974)

In essence the pilot has direct control of the innermost loop and acquires information on the effects of control inputs on the hierarchy of sub-goals after sucessively greater periods of time. For example, if the pilot moves the stick to the side he is immediately aware of the change of the control and of the control surface to which it is attached, i.e., the ailerons. Eventually he will return the stick to center. During the process, after the control is moved, he becomes aware after successively longer periods of time, of a change in bank rate, bank angle, heading and finally, position.

Jensen (1979) introduced a control model analysis of piloting tasks as a prelude to investigating the effects of different types of predictor instruments. He hypothesized that although the pilot controls his aircraft from the inner loop outward, he makes his predictive decisions from the outer loop inward. That is, the pilot successively estimates the position change necessary, the heading or directional change necessary to achieve the desired position, the bank angle necessary to produce the heading change and finally the amount of aileron control necessary to produce the bank angle.

From the foregoing, several points are worth highlighting. First, both the goal-directed and controller model of flying behavior recognize the value of characterizing behavior as a continuous, cyclic process of information acquisition, decision and execution. Second, consideration of the the information acquisition process is limited to stating generic information requirements (pilot-centered requirements) and nothing more. Both types of analysis state what information is needed but nothing about how, when or from where it is acquired. Third, the controller model shows clearly that the information acquisition and execution phases of the outer loops are remotely linked in time. That is, the consequences of information acquired (and decisions made) about position, for example, do not become immediately manifest in the execution of control movements by the pilot. The consequences become apparent, i.e., feedback is obtained, only after, and due to, a sequence of inner control loop events.

FLIGHT TRAINING

Flight Training Objectives

Flight training objectives also tend to be stated in pilot-centered terms which emphasize the procedural and control aspects of flying. Training objectives state what the pilot will be able to accomplish. Rarely, if ever, are the environments in which he is expected to perform (and from which visual information is to be acquired) described except in the grossest terms, i.e., shorebased, shipbased, night, day. The implication is that the information required to perform in these environments will be afforded either by the aircraft instruments or by visual sources in the natural environment.

The object of flight training, whether in an aircraft, a simulator or a classroom, is defined as teaching which results in the pilot being able to make the right responses at the right time in the aircraft (Roscoe, 1979). Flight training is supposed to consist of teaching cognitive skills, procedural skills and perceptual-motor skills (Roscoe,1979). The perceptual-motor training component is training to maneuver the aircraft with the primary flight controls. Most of the emphasis of training, however, is on the motor side rather than the perceptual side of this behavior. There are two probable reasons for this. First, the aircraft behavior and pilot behavior are observable by the instructor but how or from what the student pilot is acquiring information is not. Second, since no one knows for sure what sources pilots use to acquire visual information or how perceptual processes work there is no evident method of giving instruction on how or what to perceive.

When flight training is conducted in a simulator it is typically employed as a substitute for an aircraft rather than as a training device which affords unique opportunities for improved instructional strategies (Caro and Prophet, 1973). Because flight simulators are thought of as aircraft, the methods of training used in flight simulators duplicate or parallel those used in aircraft. A predictable consequence of this attitude is the assumption that a flight simulator visual system should present a scene to the pilot essentially identical to what would be present if the training were being conducted in an aircraft rather than in a simulator.

Earlier it was said that the importance of the visual system requirements and trade-off decisions they require were not fully appreciated by people who determine flight training objectives. From the foregoing it appears that this lack of appreciation stems from three circularly related reasons. First, flight training objectives and the conduct of flight training in both aircraft and flight simulators emphasize pilot-centered factors. In keeping with the pilot-centered orientation, information requirements are stated. These are inappropriate. Information sources are what must be specified. Second, since the processes of acquiring and using visual information are poorly understood there is insufficient knowledge to properly state the functional requirements for a visual system. Also, for the same reason, it is difficult to formally instruct on information acquisition processes during training. Third, training in a flight simulator is approached in much the same way as training in an aircraft. So what constitutes the pilot's environment in the aircraft, including the visual world, is tacitly assumed to be necessary for simulator training.

Procedurally Oriented Flying

A pilot's training consists of several successive stages which proceed from basic familiarity with the layout and functions of the cockpit equipment to utilization of the aircraft to achieve some mission purpose. Throughout flight training, great emphasis is placed on doing things the right way at the right time. In other words, flight behavior is proceduralized throughout.

To accomplish flight tasks, e.g., takeoff or landing, there is a correct procedure in terms of control actions and the achievement of desired aircraft states. For more comprehensive flight functions, i.e., mission employment, proceduralized flight tasks are strung together in an appropriate sequence to achieve the flight objective.

The correct procedures for any given flight task remain the same with very little difference due to the environment in which the pilot is operating. For example, approaches and landings involve many of the same procedures regardless of whether the aircraft is being operated during the day or night or whether it is operating from a shore based airfield or a ship at sea. The only important differences in the accomplishment of the task procedures in different environments is the visual information sources the pilot must use to accomplish his tasks.

The object of having the pilot perform in different environments is not to learn new procedures but rather to perform the same procedures while using different visual environments. Typically, this is done by exposing the pilot to these different environments. The pilot learns to associate a variety of information sources with specific procedural tasks.

Training pilots to operate in a variety of environmental settings requires a relatively small amount of time and effort compared to that required to give the pilot basic procedural skills in the first place. This suggests that perceptual learning, i.e., the ability to generalize the application of flight skills in different visual environments, occurs quickly, relative to the acquisition of basic skills. In other words, pilots can learn to use information afforded by different environmental sources with little difficulty, once the flight control skills are acquired.

When a pilot learns to fly in a simulator, the simulator and the characteristics of the visual environment provided by the simulator visual system, is the basic setting in which the pilot learns his skills. The real world is a change of visual environment in which the pilot learns to generalize the application of the flight procedure skills he has learned. In effect, the real world can be considered as the changed visual environment in which the procedural skills are generalized. If

this assumption is correct, then the characteristics of the simulated scene may not be of critical importance as long as the information required to learn flight procedures is afforded by the scene.

Pilots, like all adult humans, have a great deal of experience in acquiring information from the real world. Once a pilot acquires flying skills in a simulator, the experience he has in perceiving the natural world should greatly facilitate his learning to acquire the information he now knows is important to his tasks from the natural world.

Consider the implications of having a realistic vs. a non-realistic visual scene presented during flight simulator training. It is assumed that both types of scenes afford the required information. If a visual system which presents a very realistic scene is used, i.e., one which looks like the natural world, the pilot trainee will develop his flight procedural skills in a visual environment very much like the one which will be experienced in the aircraft. When the pilot finally transitions to the aircraft, the perceptual learning required to generalize the skills will be minimal.

If, on the other hand, the simulator visual system presents a very non-realistic scene, the pilot trainee still will be required to learn the flight procedural skills and also will be required to learn to use the novel information sources afforded by the non-realistic scene. When the pilot transitions to the aircraft, he will now be required to learn to use natural sources of information to execute the flight procedures. Because of the pilot's lifelong familiarity with perceiving the natural world, however, it can be expected that learning to use real world sources of information will occur very quickly. That is, the perceptual learning which must occur when the pilot is exposed to the real world, may not require significantly greater time or effort than that required for the pilot who is trained in a simulator with a realistic visual scene.

Pilots have been trained to fly by use of the cockpit instruments before they were trained in visual contact flight. Cockpit instruments afford required information for (many but not all) flight tasks. Instrument flying is visually as non-realistic as it is possible to be. Studies have shown however, that training to fly by reference to instruments before visual contact flight consistently facilitates the acquisition of visual contact flying skills (Caro, Isley and Jolley, 1973: Caro, 1977).

If perceptual learning does occur quickly when the pilot is exposed to the real world, the use of a realistic scene during simulator training may be unnecessary and not cost effective. Realism does not come cheaply and there is no point in paying for it unless it is justifiable in terms of training

value. As has just been discussed, there is reason to question if there is any significant training value which justifies the cost of visual realism.

Questions

Bridging the gap between the pilot referenced visual information requirements and the world referenced visual system functional requirements is a complex problem. What kind of information the pilot requires to perform his task is fairly clear. That this necessary information is afforded by a real-world scene is also clear. What is obscure is how the information is afforded by the sources and how the pilot acquires visual information.

A relevant question is whether realistic representation of the natural world scene is the only way that visual information can be afforded to a pilot during flight training in a simulator. This question, in turn, raises the question of what is the purpose of training in a flight simulator? More explicitly, is the object of flight training in a simulator to teach the pilot to control the aircraft, regardless of how the information necessary to do this is provided or does the purpose of simulator flight training also include the requirement to be able to learn to control the aircraft by use of visual information afforded by a natural scene? A simpler form of this question is why are visual systems necessary for flight training simulators? The next section addresses some of these questions by considering how visual system requirements might be developed and what the published literature on visual simulation and visual perception contribute to solving the problem of specifying visual system functional requirements.

SECTION IV

VISUAL PERCEPTION OF REAL AND SIMULATED SCENES

INTRODUCTION

Properly specifying the functional requirements for a flight simulator visual system involves bridging the gap of knowledge between the information requirements and sources. This effort must necessarily address the two related subjects of affordance of information and acquiring of information through vision.

One approach to determining what sources of information are required is to try to determine what these sources are in a logical manner based only on the information requirements. As will be seen, this approach fails rather quickly. A second approach is to examine the literature on visual simulation and visual perception, to determine what has been discovered about the uses of visual systems to support flight training and the processes of visual perception as they relate to supporting real world activities such as flying.

Both of these approaches are presented in this section along with some excursionary discussion about the nature and value of the literature as it applies to specifying visual system functional requirements. This section will end with some statements about visual perception which appear relevant to the development of the research issues discussed in the following section.

VISUAL SCENES FROM MINIMUM INFORMATION REQUIREMENTS

The initial approach taken to relate visual information source requirements to visual information requirements was to determine what features a scene must minimally contain to provide the necessary information for a particular flight task. For discussion purposes, consider the general flight task of landing which requires, among other things, information about orientation and local ground position. The pilot needs to know the attitude of the aircraft, and his position with respect to a runway of a given size.

Minimum Scene Requirements

The logical development of what a scene must minimally contain to provide the required information could go as follows. Starting with a homogeneous field of light, the pilot needs something to tell him up from down. A horizon line, infinitely extended, would differentiate the sky from the ground; a difference in brightness between sky and ground would make each distinct over the entire field of view. The pilot

now has been afforded a source of pitch and roll information. Add a point, say on the ground plane, and the pilot also is afforded yaw information. Extend the point to a finite length line and the information afforded includes heading and position (both 180 degrees ambiguous), altitude (the line has a finite length), range to the line, and relative speed. Without carrying this analysis any further it can be seen that this type of reasoning leads to a very sparse visual scene which, in a formal sense, fulfills all the information requirements. In fact, for the task of local positioning during landing, the horizon line and runway shown in Figure 4 satisfies all the information requirements. A similar scene has been shown to be effective for the training of landing skills (Payne, et al., 1954).

Adding Features To The Scene

Objections can immediately be raised, however, that such a scene would be useful only if the runway was in the field of view, and it is doubtful that the pilot would be able to get sufficiently accurate speed, altitude and distance information to land the airplane; at best, it would be difficult. These are reasonable objections from a practical point of view.

It would be easy to add more features to "help" the pilot. Texture of the ground plane would help, as would the addition of markings on the runway. Natural and cultural features could be added, etc. The problem is that it is difficult to state an objective rationale based either on logic or on published literature, for determining what else is needed in the scene and why. The only study to demonstrate the value of adding more features was performed by Eisele, Williges and Roscoe (1976). They found that judgment of position relative to a desired touchdown point during landing approach was more accurate when a runway centerline was present and the aircraft was very near the threshold, and when a synthetic representation providing glideslope and lineup information was present at all approach distances. Common experience, such as pilot recommendations, and designer judgments have been the primary bases for justifying the addition of features to the visual scene.

Simulator visual systems are designed in this way, but some seem to do the job better than others. Futhermore there are insidious aspects to this so-called "pragmatic" approach. "Additional features" usually translates to "more realism" which is justified by the assumption that it provides greater training value. Unfortunately, there is no hard evidence to substantiate this common assumption (Caro, 1977; Waag,1979).

The pilot experience and/or designer judgment methods for determining simulator visual system scene content and display characteristics mean that there is no objective, systematic

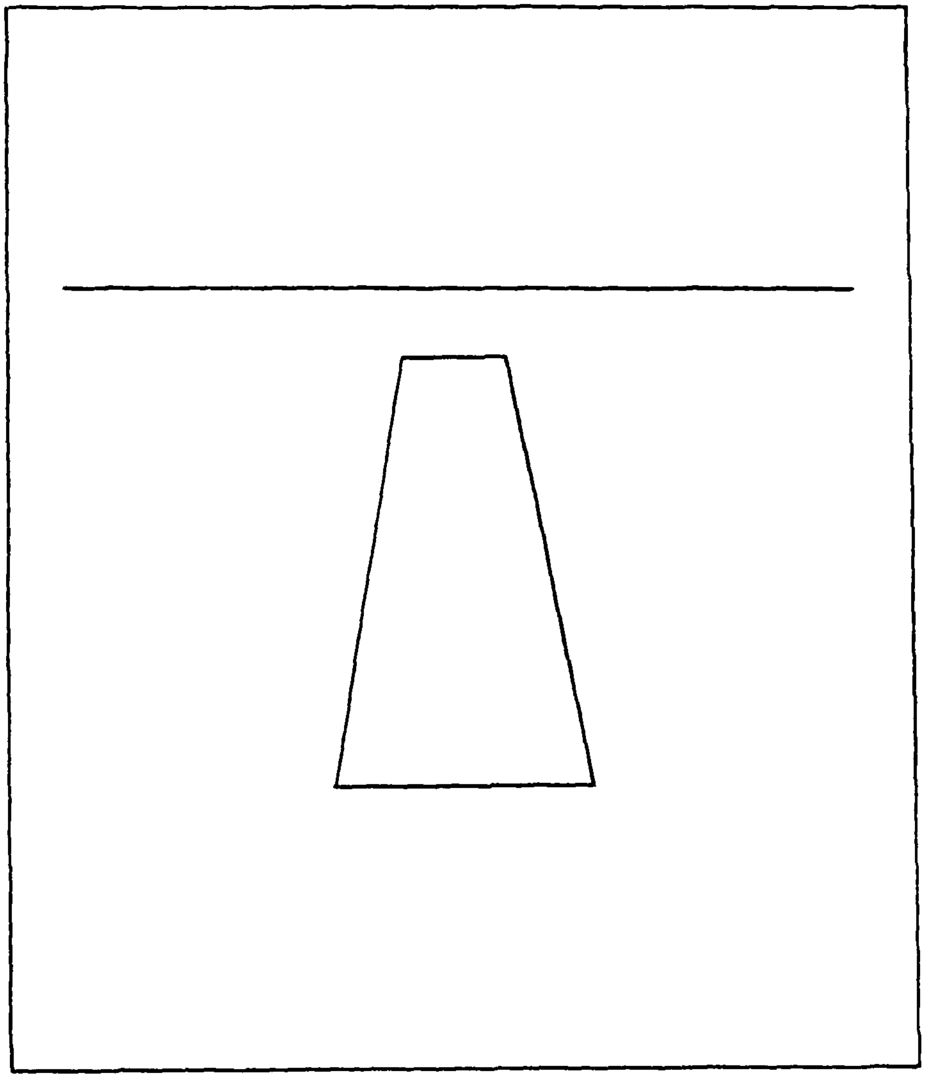

Figure 4. Minimum scene which satisfies all visual information requirements for landing task.

method which can be developed and built on. Knowledge of visual system requirements is resident in the heads of experts and not subject to public scrutiny. Each new visual system is a unique production. Visual system design therefore has more of the characteristics of artistic development than of scientific development.

A logical analytic approach to developing visual system functional requirements does not get very far. At some point the knowledge gained from past experience with visual systems, particularly research experience, and knowledge about visual perception must be considered to proceed with the development of visual system requirements.

VISUAL SIMULATION LITERATURE

A review of the literature on visual simulaton and visual perception revealed that remarkably few reports are directly relevant to the development of the functional requirements for simulator visual systems (Semple, et al., 1980). The reasons for this will be discussed presently. The conclusions reached from the literature review are: 1) there is little evidence to support the need for realistic visual scenes for flight training; 2) the majority of the reports on visual perception are on psychophysical aspects of vision and the metrics of visual space perception, but these contribute little to the understanding of the process of visual information acquisition in support of purposeful, real-world behavior. After discussion of the nature and limitations of the literature, general characteristics of vision which appear to be relevant to the development of functional requirements for simulator visual systems and to the formulation of critical research issues will be presented.

The visual simulation literature can be regarded as falling into five general topic areas:

1) Visual system technology.

2) Description of simulator visual systems.

3) Design requirements for simulator visual systems.

4) Experimental studies of the effects of visual characteristics on aircrew performance.

5) Theoretical or review papers on pilots' visual requirements and/or visual perception.

Most of the literature, particularly in the first four categories, occurs in technical reports issued by government laboratories or government contractors. Much of the literature in the last two categories occurs in published conference proceedings, scientific or engineering journals, and books.

Most of the visual simulation literature was published in the period between about 1963 and the present.

Early Developments

Before the early 60's there was very little interest or activity in simulator visual systems because, prior to that time, flight simulators were viewed as useful for the training of non-visual tasks such as cockpit procedures, instrument flight and emergency procedures. Also, simulator technology is basically linked to the evolution of computer technology. The rapid developments in computer technology which allowed the accurate simulation of aircraft flight characteristics and the rapidly escalating costs of military and civilian aircraft operations were probably responsible for the impetus to extend the use of flight simulation training to visual flight operations.

The earliest interactive visual system was a point-light source projection (Payne, et al., 1954). This was followed by development of film and camera-model board systems. Because of their fixed flight path, film systems had, and continued to have, very limited application. Until the 70's, camera-model systems were limited to relatively narrow forward fields of view. Consequently, the primary use of these systems has been for training of takeoff and landing flight phases. Providing only a forward field of view satisfies most of the training requirements for commercial aviation training, but may be too restrictive for military flight training applications.

In the late 60's and early 70's, computer developments, particularly in graphics, promoted an interest in computer image generation (CIG) of synthetic visual scenes. The earliest applications of CIG were in night visual simulation. A night scene consists primarily of an array of points of light, and somewhat realistic looking night scenes could be created without overtaxing computational or display capabilities. Increased computational power and special computational equipment for CIG purposes in the recent past have led to the development of reasonably detailed synthetic twilight and daylight scenes. Advances in display technology in the late 60's and early 70's also provided improvements in the realism of visual scenes. The first CIG, daytime scene, simulation system used for military flight training occurred in 1972 (O'Conner, et al, 1973). Better resolution and contrast, color, larger display formats and increased fields of view greatly enhanced the capabilities and realism of visual simulation. The improvements in display technology have also greatly enhanced the capabilities of camera-model systems.

The expansion and increased use of visual simulation has promoted the division of visual system technology into several specialized areas of research and development. The specialities generally fall into the areas of image generation

(in the case of CIG), image pickup (in the case of camera-model systems), image transmission, and image display (projection and direct viewing). A few recent visual simulation systems are hybrid camera-model and CIG systems.

Pursuit of Realism

The history of flight simulator development, including visual system development, is the history of the pursuit of fidelity and realism. Fidelity and realism are not used synonymously here. Fidelity is taken to mean that the visual simulation is accurate. Realism is taken to mean that the simulation is not only accurate, but comprehensive. For example, the perspective, size and dynamic transformation of the runway image synthesized from four lines can be completely accurate, i.e., have perfect fidelity. The image, however, would not be considered realistic since the scene would be completely devoid of all the other visual characteristics associated with a cockpit view of a runway.

The validity of a simulation, in terms of fidelity and realism, has been and continues to be based on the judgment of pilots experienced in the aircraft being simulated. Rightly or wrongly and for a variety of reasons, pilots are extremely critical and skeptical of visual simulations which are not realistic. In the absence of alternative definitions of the goal or purpose of visual simulation, realism has been requested in procurements, and industry has devoted a large part of its research and development efforts toward providing greater realism.

The pursuit of realism, implicitly or explicitly, dominates the visual system engineering literature. The behavioral and training literature on visual simulation is dominated by concerns about what realism is, what is necessary to achieve it (from the pilot's point of view), and what is it good for? Implicit in analytical or research reports about pilot information requirements for various flight tasks are concerns about what visual cues provide the information to the pilots, and how the presence or absence of particular visual cues affect pilot learning and performance (Conant and Wetzel, 1970). Pilot information requirements for a given task are relatively easy to define. How the information is extracted, and from what source, in a real or simulated visual scene is basically unknown. What visual cues are and how they are used cannot be specified in an objective manner.

Engineering Descriptions

There is a large gap between the engineering or equipment oriented literature and the trainee or behaviorally oriented literature. The first two categories of literature, visual system technology and descriptions of simulator visual systems, describe the development and performance of components of

visual systems or the configuration and performance of the entire visual system. This literature basically presents what a piece of equipment will do. Performance specifications are generally in physical terms, i.e., resolution, contrast, bandwidth, computational rates, linearity, distortion, total number of points, edges, surfaces, or solids.

Design Requirements

The third category of the literature, design requirements for simulator visual systems, usually contains sections entitled "review of the visual literature," "visual requirements," or the like. Generally, these papers cover visual sensory sensitivities, i.e., central and peripheral acuity, contrast sensitivity, motion sensitivity, etc. Then, usually in a non-sequitur fashion, visual cue and scene composition requirements are discussed. A litany of the information and cue requirements for attitude, position and rate information is given, followed by a description of the requirements for visibility of an airfield, target, other aircraft, etc., as applied to the task training requirements. Having made the obligatory review of the pilot's visual capabilities and requirements (usually a very short chapter or section), the equipment design and specifications follow.

Design decisions are made, which are purely judgmental, which attempt to relate the equipment requirements to the scene requirements for a realistic presentation. This is not the fault of the design team. Decisions must be made about how the visual system will be constructed, and the literature on vision and visual perception is simply too vague and non-objective to be of much help to the designer. Providing a hardware visual system that meets or exceeds the human visual sensitivities, and producing the greatest amount of potential detail in the widest field of view is about all that can be expected. Many of the judgments made by designers, in the absence of appropriate data on which to base their decisions, are, at least superficially, reasonable. For example, the need for extensive detail in the ground scene in an air combat simulator would generally be considered inappropriate by the designers, the customers procurement and training personnel, and operational pilots. Good, bad or indifferent, these decisions are made, because they must be, but they do not evolve from the visual and/or training literature. In most cases the literature does not contain the required information or, even if it appears to contain the required information, the designer (or procurement officer) does not know how much credence should be given to it. This problem will be discussed further later on.

Experimental and Theoretical Literature

The information of most relevance to visual system requirements for flight simulators comes from the few experimental studies of effects of visual system characteristics on pilot performance and from the theoretical or review papers on pilots visual requirements and/or visual perception. Waag (1979) has published a recent review. There are few reports which address the effects of systematic manipulation of display characteristics or scene content on pilot performance or training effectiveness as revealed in subsequent testing in actual flight (cf: Payne, et al., 1954; Eisele, Williges and Roscoe, 1976; Lintern, 1978; Randle, Roscoe and Petitt, 1980; Nataupsky, et al., 1979). The oldest study (Payne, et al., 1954) involved the assessment of the transfer benefits of the presence of a specific visual scene per se. Many studies deal with the effect of delays of motion in the visual scene following control inputs and mismatching between motion base and visual scene movement. A few studies have been done on distance and depth perception in simulated scenes (Palmer and Petitt, 1976; Kraft, Anderson, and Elworth, 1977; Kraft,1979; Buckland, Monroe and Mehrer, 1977; Randle, Roscoe and Petitt, 1980).

No transfer of training studies, other than the Payne, et al., study (1954), address the issue of the value of the presence of an external visual scene, per se. If there is a visual system on the training simulator then its need per se is unquestioned. Most commonly, transfer of training studies involving a visual system address the utility of the visual system as a function of the presence or absence of a motion system. Waag (1979) has produced a comprehensive review of this work. Two studies have been performed on the effect of the presence of artificial or augmenting cues during the training process (Lintern, 1978; Hughes, 1978). Most of the experimental studies involve the approach and landing phases of flight.

The amount of work on visual scene quality and content and its relation to training effectiveness seems inordinately small. The paucity of experimental literature on visual system effectiveness is probably the result of the emphasis on the development of complex simulator technology and the lack of research simulators of sufficient reliability and manipulative flexibility to support meaningful experiments. While several research and development simulators exist, most are devoted to research and development on aircraft handling qualities, cockpit design, or other engineering considerations. It is little wonder that there has been such a small amount of research on the effects of visual system characteristics on pilot training and performance.

Training simulators, though generally reliable, are not designed for the easy, systematic manipulation of variables, and have not often been used for research purposes. Training simulators are built to train, and any research conducted is usually a by-product. Once the simulator and its visual system exist, there is little perceived value in determining whether a visual system with lesser or different capabilities would be as effective for training purposes.

Recently, procurement of simulators equipped with visual systems has increased dramatically, in both the military and commercial aviation fields. At the same time, visual systems have become more sophisticated and more costly. For both of these reasons, the question of what features of a visual system are really necessary to support flight training, has become increasingly important. As a consequence, probably more research on visual system characteristics is currently underway or planned than has been conducted in the past twenty years. Much of the experimental work that has been conducted is important, but has had little impact on visual system design or procurement decisions.

THE PROBLEMS OF USING RESEARCH RESULTS

Few experimental findings can be generalized from the specific experimental circumstances to other aircraft, simulators or training curriculums. Generalization and acceptance of findings usually occur when several studies conducted under widely differing circumstances come to the same conclusions. Also, a very important consideration in assessing the results of any study is the way performance is measured.

For example, in a well designed and executed study of varying levels of texture in a runway visual scene (Buckland, Monroe and Mehrer, 1977, 1979), the results were that sink rate at touchdown improved (was less) with decreasing size of texture elements. The smallest sized elements (4 ft. squares) produced the best performance, a sink rate of 147 ft./sec. at touchdown which was still considerably higher than the typical sink rate of 33 ft./sec. at touchdown in the aircraft.

An immediate question is whether the measure used is valid. That is, does sink rate predict general transfer performance in the actual aircraft and not merely reflect performance in the simulator? Second, would performance even be better if even smaller texture elements were used? Will the amount of texturing in the training simulator have an important effect on time required to become proficient in the actual aircraft? The reader or user of a report of this kind can only rely on his own judgment. Presuming there is an increase in cost associated with the greater detail of texturing, what decision should the designer of a new simulation system make about the required level of texture, given this information?

Transfer of training studies between a simulator and the aircraft are expensive and time consuming. That it is essential to do this kind of study has long been recognized but seldom carried out. Without this information how much reliance should a visual system designer or procurement officer place on the ground based results? Secondly, should the system designer assume that the results of a single study are applicable to the system he is working on when the purpose of his system may be somewhat different from that of the system on which the research was conducted?

VISUAL PERCEPTION LITERATURE

Knowledge about vision and visual perception falls into several loosely defined areas such as physiological optics, sensory processes, psychophysics, neurophysiology, perception of space, motion and color, form perception, visual search, perceptual learning, developmental perception, visual information processing and cognitive processes. Large numbers of research reports exist, which contain extensive bodies of knowledge on each topic. There are many micro-theories that cover limited areas of visual processes or visual perception. It is safe to say, however, that no single comprehensive theory of vision takes all of visual perception into account.

A distinction, useful for purposes of this work, is made between psychophysics and perception. Psychophysical research is the study of the relationships between quantifiable physical stimuli and their effects on behavior. If a stimulus cannot be quantitatively defined, the relationship between stimulus and behavior cannot be adequately described for pyschophysical purposes. Perception is a broader term which applies to all processes by which information about the world is obtained. Psychophysics would normally be considered a subdivision of perception. Here, however, the term perception will be used to emphasize the information acquiring aspects of vision as contrasted to psychophysical sensitivities to stimulation.

Fundamental visual sensitivities, psychophysical processes, have been studied extensively. The results are quantitative, have been repeated numerous times, and are usually related to visual system requirements. Many of the concepts of visual sensitivity and simulator visual system performance are identical. Resolution, contrast, angular subtense, color (chromaticity coordinates) mean the same thing to the visual scientist as they do to the engineer.

When experimental or analytic studies are undertaken to investigate simulator visual system requirements, the work is often limited to psychophysical aspects of simulation, e.g., Kraft, Anderson and Elworth (1979). Although the work performed is of high quality the authors state very early that

no consideration will be given to issues of scene content. Visual system engineers will no doubt find this work very satisfying and easy to understand because the topic is limited to characteristics of the display, not to what is or should be displayed. The terminology of the authors and engineering readers is the same and the research issues discussed are concrete and unambiguious.

The understanding of visual perception has not advanced very much in the past fifty years. Perception is generally discussed in very general and qualitative terms. Quantitative work on perception such as size and distance perception, shape perception, recognition and identification of objects (targets) is useful and is suggestive of some of the fundamental conditions that must exist to give rise to these perceptions. Large individual variations in sensitivity to situational specifics and the narrow and artifical conditions under which much of the fundamental visual perception research has been conducted, present difficulties when an attempt is made to extend the work on visual perception to the requirements for a visual simulation system. For example, there is no commonly accepted definition for the term "visual cue." In the perception literature, visual cues refer to such things as size, interposition, motion parallax, binocular disparity and the like. In the visual simulation literature the term visual cue has been applied to trees, lakes, texture, targets, rescue operations, aircraft attitude, and visual landing aids.

Almost all knowledge of visual perception comes from research, and the research is limited in scope. Therefore, the findings from research can be generalized only within narrow limits similar to the conditions under which the research was conducted. This disappointing state of affairs exists because of the accepted standards of what is good research. The emphases in visual research (and experimental psychology in general) are essentially the same as they are for the physical sciences. The key standards are control of conditions, manipulation of one or, at most a few variables (Simon, 1978), and certainty beyond reasonable doubt that obtained results are reliable, i.e., repeatable and valid, i.e., attributable to the manipulations performed.

The consequence of these standards is a great deal of confidence in very limited knowledge. In formal terms, whenever the value of an important variable is "controlled" the measurement "effects" of the "experimental" variables are valid only in applications involving the same fixed values of the uncontrolled variables. The inability to generalize to conditions where the uncontrolled variables have different values makes the knowledge gained in the experiment worth next to nothing for all practical purposes.

When a somewhat global, real world activity, such as flying by visual reference, is analyzed, there is no current way of relating the compartmentalized knowledge of visual perception to the overall effect on the pilot's performance. The problem is compounded for flying in a simulator with a visual system because the pilot is perceiving via a picture of the real world. Knowledge of visual perception is not sufficient to determine what is necessary to provide in a visual simulation because there is no systematic way of relating the several bodies of knowledge within the various areas of visual perception to real world situations where all these processes are operating simultaneously and uncontrolled factors abound.

Trying to relate fundamental knowledge to a complex, real world activity has always been a problem for both engineers and psychologists working on applied problems in man-machine systems. University researchers have also become increasingly concerned about the lack of relevance of the knowledge gained from theoretical or "pure research" studies to everyday human activities. Recently there have been strong statements made that psychological research should be aimed at the larger issues of behavior as manifest in real world conditions and should get away from the certain but limited value studies typical of most laboratory research (Gibson, 1966, 1979; Neisser, 1976; Simon, 1978; Gibbs, 1979). It is not necessary to forsake all certainty or control to do more generally relevant research, but it does require thinking about major aspects of human behavior, such as visual perception, in broader terms, and the development of new research strategies.

If there is a convergent structure of knowledge about visual perception with a large volume of fundamental data subsumed under a hierarchy of simplifying explanatory statements, i.e., theory, then the most serious gap in this knowledge seems to be near the top. What is needed to fill the gap is some general theory which relates perception to behavior in general. There seem to be only two general views of perception which can be conveniently categorized as the classical and modern views of perception. Neither the classical nor the modern view provides an explanatory general theory of perception. Rather, they provide concepts about the method of approaching the problem of studying vision. The classical view is based on the premise that if vision is studied by comprehensive investigation of the visual processes from eye to brain, an understanding of perception in general will ultimately result as a natural consequence of understanding the details. The modern view is based on the opposite premise. There must be some notion of how perception subserves natural behavior first, before any meaningful attack can be made on understanding the details of perceptual processes.

Classical Perceptual Theory

The classic view of perception is that light enters the eye and stimulates the retinal receptors which in turn produce neural signals representing the stimuli which build up into perceptions. In more contemporary terminology the input stimuli are encoded, processed into features, integrated with memory information, and a perceptional output is produced. Whatever words are used, the general concept is the same. Perception is conceived to be a hierarchical processing of input signals which are influenced at one or more stages by memory. The perceptual system is viewed, in effect, something like a factory. Raw materials enter one end and finished products come out the other. You discover the nature of the factory by dropping selected items into the intake chute and seeing what comes out.

The direct consequence of this kind of thinking is the research practice of investigating perception by noting the consequences of the presentation of static stimuli for a brief duration. It is believed that if you do this in a sufficiently comprehensive and systematic manner, the result will be a functional description relating the visual inputs to the perceptual outputs. Perceptual development is seen as the building of memory traces through experience, which eventually results in mature perception.

The methods of research and the conceptualization of perception go hand in hand. Each influences the other. A great deal has been learned about the mechanics of visual perception through classic neurophysiological and psychophysiological research guided by some variation of the classical viewpoint of perception.

For the present work, the important practical consequence of the classical view of perception is that thinking about, and research on, perception is generally confined to the narrow range of activities common to the visual research laboratory. The point is that not only is our knowledge of visual perception fragmented and restricted as a consequence of the accepted methods for conducting research but that the ways of speaking, writing and thinking about perception also have been limited for the same reasons. Because this limitation of thought is implicit, most laboratory perceptual research is conducted comfortably without noticing how narrow the classical courses of inquiry really are. This restrictiveness of perceptual thought, research and knowledge becomes very apparent, however, when an attempt is made to understand, and perhaps predict, the perceptual requirements for performance of a complex real world task such as flying an aircraft or learning to fly by visual reference in a simulator.

Modern Perceptual Theory

The key feature of modern perceptual theory is that it takes a wide view of perception as it operates in complex everyday human behavior. Perception is regarded as an on-going interaction of a person with the environment. The emphasis is on the dynamic character of the perceptual cycle as an indivdual moves about in and interacts with his environment. Human behavior is purposeful and perception is the information gathering part of purposeful behavior. Perception is the principal means by which we come to know about the world in ways that are relevant to us as living creatures. When perceptual information is acquired it is always information about the world that is relevant to the individual as part of the world. Perception is an interaction between the perceiver and the world. The perceiver and the world perceived are inseparable.

The proper subject matter for the study of perception is the information acquiring activities that occur during the interaction of an individual with the natural world for some purpose. Placing people in artificial settings, constraining their activities and giving them artificial purposes may be a comfortable and useful way of studying visual processes, but probably will contribute very little to our understanding of perception.

The above statements are strongly stated, but fairly represent the chief characteristics of modern perceptual theory as contrasted with classical theory. The modern theory emphasizes that perception can only be studied and understood as part of real world activities.

The modern theory of perception has principally been advocated by James J. Gibson (1966, 1979). Looking at perception in terms of its relation to real world activities is referred to by Gibson as "an ecological approach to perception", which happens to be the title of his most recent book (Gibson, 1979). Another influential advocate of the modern theory of perception is Ulric Neisser (1967, 1976) whose interest is mostly in cognitive aspects of perception.

The modern theory of perception as represented by the statements of Gibson and Neisser is rather broad and not formulated in such a way as to be testable by some crucial experiment. Its acceptance will be more a function of its utility as a structure for comprehending a wide variety of perceptual phenomena, and for suggesting new approaches for perceptual research. Under the influence of modern perceptual theory a substantial amount of research has already been conducted (e.g., Pick and Saltzman, 1978). The present work draws on modern perceptual theory in an attempt to understand the general role of perception in flying and flight training.

The features of visual perception relevant to simulator visual system functional requirements, to be described presently, are based on the modern view of perception. These statements are considered eclectic and descriptive, rather than systematic and explanatory. Their purpose is not to explain data but to provide a framework for understanding perception in the practical service of behavior such as flying in aircraft or learning to fly in simulators.

Relevant Features of Visual Perception

1. Perception is part of a continuous cycle of purposeful behavior.

Perception is the process of information acquisition which is inseparable from the processes of decision and execution which make up the cycle of purposeful behavior. Perception does not operate discretely nor is perception necessarily limited to instantaneous processes of information acquisition. Although it is a common technique of visual research to present brief, static stimuli, this is an abnormal situation. Real world perception occurs as part of the continuing behavioral cycle and perception may require a considerable amount of time. It is not necessarily instantaneous.

2. Information, not sensory impressions, is perceived, and the information that is perceived is defined by how the information is used, i.e., the purpose of user at the moment.

Sensory impressions are not building blocks of perception. There is no need to believe that all the information afforded by a scene is processed and the irrelevent information discarded. A user will extract from a visual scene only the information that is required for some purpose. This information may be derivable in more than one way. Information is not an inherent characteristic of an object or an arrangement of objects in a scene. Information in a scene can only be specified in terms of how the perceiver uses the information.

3. People actively seek information.

Perception, the acquiring of information about the world, is an active process. It is not the result of simply processing the image on the eye. Movement of the eyes, head and body are the obvious physical manifestations of the information seeking process. Not all seeking of information, however, is apparent from eye, head, or body movements.

4. There appear to be at least three levels of perception: 1) image referenced, 2) world referenced, and 3) knowledge referenced. These levels of perception are

distinguished by the type of information acquired and the ease with which each level of perception may be modified by perceptual learning and experience.

Type of information acquired. The levels of perception may be part of a continuum rather than discrete. Perceptual activities, however, seem to fall conveniently into one of the three categories listed.

Image referenced perception means perception of the characteristics of the optic array i.e., the pattern of light entering the eye. Color, contrast, shape and movement can be perceived in the pattern of light without reference to particular objects. Information is perceived about the arrangement and character of the optic array without direct perception of information about the world.

World referenced perception is the perception of things in the world. We see trees, ground, sky, people, buildings, etc. We perceive the world as a stable arrangement of things that maintain their character independent of our point of view or movement in the world. Constancy is the key feature of real world perception. Things maintain a stable spatial arrangement, size, shape, distance and color. Plastic objects such as living things, water and clouds maintain an integrity independent of their changes of form. When we move about in the world on foot or in a vehicle we perceive our motion through the environment. Again, the world is stable and we perceive ourselves as moving. We also perceive object motion which is typically characterized by a stability of most of the world except for the objects in motion.

Knowledge referenced perception means the perception of meaning, significance, intention or consequence. For example, we perceive a smile as meaning friendliness. We perceive the danger at the edge of a cliff. Perception at this level means not perceiving things per se but rather the actual or potential significance for our own behavior.

Perceptual learning. Distinctions have been made between levels of perception based on their apparent functions which range from the fundamental sensitivity to light to the highly abstract functions of awareness of intention and situational significance. Beside the functional differences there appears to be a very strong relation between perceptual levels and the degree to which the functions they subserve can be modified by experience.

The image referenced level of perception appears to be subserved by innate mechanisms and cannot be changed appreciably by experience. This is certainly true of sensitivity to light, contrast discrimination, color discrimination, relative position of objects in the image field, and the detection of movement or change.

Neurophysiological correlates of these lower level perceptual functions are evident. Retinal receptor cells have different spectral sensitivities. Discrete channels which are selected for spatial frequency have been identified. Cells throughout the visual system have been found which are differentially sensitive to different types of movement and pattern (Sekuler, 1974). At the image referenced level of perception only very weak and transitory effects can be produced by experience such as figural after-effects. For example, after staring at a curved line for some time a straight line will appear slightly curved in the opposite direction for a short while.

The world referenced and knowledge referenced levels of perception are highly susceptible to modification by experience. At the world referenced level, experience is necessary for the initial development of the perception of a stable world in the identification and recognition of objects. Size and distance perception must also be learned. The size and distance perception of children does not approach the accuracy of adult perception until 11 or 12 years of age.

In addition to initial development, world referenced perception is easily changed by visual experience. For example, people can achieve a stable perception of the world even when it is drastically modified by wearing optical devices which make the world look upside down. A considerable period of time, more than a week, is required to adapt to the inverted optical array. After this period of time normal perception of the world is achieved even though the image of the world is rotated 180°. That is, information about the world is acquired with no difficulty and activities such as riding a bicycle can be accomplished with the same proficiency as when the normal image of the world is available. In agreement with the concept of levels of perception, the observer is aware of the inverted image when he attends to the image, but is unaware of it when he goes about his normal activities which primarily depend on world referenced and knowledge referenced perception.

At the knowledge referenced level of perception, modification of perceptions can occur quickly and do not require visual experience for the change. The significance of an object or situation can be changed by verbal instruction as well as by experience through visual observation. For example, behavior in the presence of a dog will be very different depending on whether the person has been told the dog is friendly or apt to bite.

The concept of levels of perception appears to be supported by both the referrent of the perception and by each level's relative amenability to change through experience. Describing visual perception as consisting of several

functional levels with different characteristics of amenability to change through experience is very useful for considering the requirements for a simulator visual system, as will be seen at the end of this section. The levels of perception and characteristics just described are summarized in Table 13.

TABLE 13. CHARACTERISTICS OF THE THREE LEVELS OF PERCEPTION

I. IMAGE-REFERENCED PERCEPTION

A. Definition: Information acquired about visual field relative features of the optic array as opposed to information about things. Relatively impervious to perceptual learning effects.

B. Examples:

1. Brightness	2. Color
3. Contrast	4. Binocular Depth
5. Pattern	6. Pattern Change
7. Form	8. Movement
9. Figure-Ground Separation	10. Relative Position in Visual Field

II. WORLD-REFERENCED PERCEPTION

A. Definition: Information acquired about features of the world. Susceptible to perceptual learning effects through visual experience and exploration.

B. Examples:

1. 3-D Spatial Continuity	2. Distance
3. Direction	4. Position
5. Object Constancy	5. Size Constancy
6. Shape Constancy	7. Color Constancy
8. Brightness Constancy	9. Object Movement
10. Orientation	11. Locomotion

III. KNOWLEDGE-REFERENCED PERCEPTION

A. Definition: Information Acquired about features of the world which depend on prior experience or knowledge of the observer. Readily susceptible to visual perceptual learning effects and non-visual learning.

B. Examples:

1. Recognition	2. Identification
3. Symbolic Interpretation	4. Meaning
5. Significance	6. Intention

5. A person can voluntarily use the level of perception which best suits his purposes at the moment.

This is simply another way of saying that a person has control over the way he seeks information. For example, a person can attend to a feature in the world as an image characteristic rather than as a real object characteristic. It may suit the purposes of a pilot to perceive the runway as a trapezoid, the shape of which gives him information about the height above the runway, rather than perceiving it as a rectangular surface on a horizontal ground plane. Or, as another example, pilots are often instructed to find the point of expansion in the visual scene to determine the direction of movement or touchdown point on a runway. In this case, the instruction is to not see the world as a stable entity but to perceive origin of the pattern of flow in the optic array.

6. More than one kind of information can be acquired simultaneously.

People can acquire information for more than one purpose at a time. The best example of this is the perception of information about locomotion while simultaneously performing another task. For example, a hunter chasing an animal through the woods can avoid objects, move around trees, and maintain his upright posture while, at the same time, watching the actions of the animal. We can walk down a hallway avoiding objects and people, while reading a book. There is a good deal of evidence that peripheral or ambient vision subserves the function of postural control and locomotion (Dichgans and Brandt, 1978), and that the function of central vision is the resolution of detail and pattern recognition (Leibowitz, et al, 1979).

7. It is possible to be aware of information from more than one perceptual level simultaneously.

This is a corollary of the previous statement applied to the three assumed levels of perception. There is no conflict in seeing more than one level of perceptual information simultaneously. For example, while driving, a car at a great distance looks very small. That is, its image occupies a very small area of the visual field. A person can be aware of the great distance of the automobile at the same time that he is aware of the smallness of its image. It is not necessary to assume that the distance is inferred because of the small size. The small image size, indeed, can serve as an indication of distance but this does not mean it necessarily does. When a strongly colored light illuminates a white object we are simultaneously aware of the resulting color due to the colored illumination, and of the whiteness of the object.

8. Perceptual learning is the acquiring of the ability to interpret the invariants in the optic array, and the education of attention.

The first part of the statement means that invariants of the optic array become associated with characteristics of the world. Image referenced perception gives way to world referenced perception.

The second part of the statement is taken directly from Gibson (1979). The education of attention is characterized principally by the ability to disregard irrelevant information and notice the information salient to the purpose at hand. Attentional perceptual learning affects information gathering behavior. The manifestations of attentional learning may be overt, i.e., where to look, or covert, i.e., what to notice about what you are looking at, or when to attend to it. In some cases it is a question of orchestration of our perceptual attention. For example, a pilot must learn what instruments must be attended to, how often, and under what circumstances. He learns not only how to interpret the instruments, but also the timing and sequence of the scan pattern.

Summary Comments on the Characteristics of Perception

Collectively, the above characteristics convey the general impression that perception operates in an active, selective and economic manner. Perception is active and selective because the purposes of the observer determine what information will be acquired. Perception is not a passive mechanism which simply carries some representation of the entire visual field to conscious attention. The observer can actively direct his visual attention to particular sources of information, although, it seems, that attention more often fixes on the information sought rather than where it comes from.

Perception is economic because more than one type of information can be acquired at a time. Also, the observer can operate at more than one level of perception simultaneously. In unfamiliar settings an observer visually and physically explores the environment in an active manner to discover how the characteristics of the optic array relate to the information about the world he is seeking. Eventually the unfamiliar relationships become familiar and the observer learns when and where he can acquire the information he wants. With experience, the acquisition of information becomes largely automatic, i.e., the amount of concious attention required diminishes.

Implications for Visual System Requirements

Because of the general nature of the characteristics of visual perception described above, they do not lead directly to visual system requirements but do suggest some things about how to think about the requirements.

The necessary information sources must be presented to the pilot. Because the same information can be acquired from many sources and the pilot will seek the information he needs, there is probably no definite set of particular sources that are always required. Also, for the same reasons, there is no apparent necessity to afford more sources of information than the minimum which will support the flight task. If the sources of information afforded are adequate to support the flight task the pilot can eventually learn to use them even if they are not similar to the sources he would use in the real world. Because perceptual learning can occur, it should not be necessary to represent sources of information in a realistic manner. On the other hand, a realistic scene offers the potential advantage of minimizing the perceptual learning that would otherwise be necessary.

It is evident from the concept of levels of perception that certain kinds of visual system characteristics must be present to be compatible with the lower levels of perceptual function. This concept also suggests that there is some latitude for choice of the characteristics of visual simulation because of the adaptability of higher levels of visual perception. The implication is that certain features of a visual simulation must be designed to match the perceptual functions of the observer. For other features, mostly related to the content of the visual scene, some design choices can be made in the interest of more effective training, of economics, or because of limitations in the state-of-the-art of visual technology.

Visual perception is very flexible. This flexibility is manifest both in the way information is acquired from moment to moment, i.e., what is attended to, and in the ability to learn to use information from unfamiliar sources, i.e., perceptual learning.

It is probably the short and long term flexibility of perception which makes the determination of visual simulator requirements so difficult. The pilots ability to control his information acquisition behavior and to become accustomed, over time, to unusual perceptual environments, such as a simulated scene, results in a very fluid set of relationships which are difficult to analyze and understand.

The situation is further complicated by the fact that a simulator visual system offers opportunities for presenting sources of information in ways which are not possible in the

real aircraft. A visual system should be regarded as a training tool which has many alternative ways of being used besides mimicking the appearance of the natural world. For example, lines can be drawn in a simulated scene which represent the desired path of the aircraft. Features of a scene can be highlighted or distorted to serve the purposes of training.

Visual systems also have characteristics which are a result of its being a medium for presenting a picture rather than a window to the world. The physical features of a visual system influence, among other things, the appearance of the picture displayed and the size (field of view) of the picture. The viewer of the display perceives not only what is portrayed but also features of the portrayal itself. At best these features are benign. At worst they may interfere with the acquisiton of information from the display. For example, a limited resolution may prevent a pilot from seeing useable detail in a scene.

The flexibilities inherent in visual perception, the flexibilities in the way visual systems can be used and the characteristics of the display all interact to affect the utility of a particular visual system to support some given training requirements. These variables all provide both opportunities for achieving training effectiveness and obstacles to understanding what visual system requirements are. Visual system requirements may not be general and independent. The requirements for scene content, for example, may depend on the task, experience of the pilot, display characteristics, training techniques and other scene content variables. The only way to find out is to conduct research that addresses all these factors in some systematic fashion.

SECTION V

CRITICAL RESEARCH ISSUE TOPICS

GENERAL

The recommended critical research issue topics fall into four categories: 1) scene content, 2) perceptual learning, 3) augmentation, and 4) display characteristics issues. Although the topics under each category will be discussed separately it must be recognized that these issues are all highly interrelated. For example, it would be difficult to do research on the contents of a visual scene without considering the ability of the hardware visual system to display the scene contents and a pilot's ability to learn to use the display during training. When discussing a particular research issue, however, the presentation would be awkward if it were constantly necessary to qualify the statements made by mentioning how the topic under discussion would be affected by a variety of other factors, many of which are research issues themselves. Consideration of what is necessary in visual simulation is a multivariate problem in which interactions have important effects.

Following the discussion of each category of topics, critical research issue summary statements will be presented which aggregate the research topics across categories into groups of variables that can be addressed in four experiments.

SCENE CONTENT

The research topics discussed in this category are based on the assumption that it is useful for training purposes to present some type of representation of the appearance of the real world. The issues are concerned with the representational features, i.e., what features are necessary to what degree to support the desired perceptions. Something must be placed in the scene to afford this process.

Gibson (1966, 1979) argues that there are invariant characteristics in the optic array (visual scene) which are not dependent upon seeing particular things in the world or seeing the world from a particular viewpoint. No matter what is seen from where a stable perception of the world emerges. The world appears to have continuity and depth, objects and places retain constant identities and the perceiver is aware of where he is with respect to the world. The images on the retinae change constantly, but the perception of the world, i.e., what the world is like, remains stable and invariant.

Scene content is probably the most elusive issue in visual simulation. There is no adequate terminology for describing the appearance of a scene, nor any agreement about what the relevant characteristics of a scene are (Thorpe, 1978). In the

absence of any solid information on scene requirements, developments in visual system technology have been pressing ahead to produce scenes with greater amounts of detail (SPIE, 1978) at greater cost. The absence of adequate concepts and definitions of scene content should not deter research on how various scene characteristcs, particularly the amount of detail, affect perception, performance, training, and training transfer to aircraft.

The exact nature of sources of information is considered to be important only to the extent that it allows and facilitates necessary and correct perception. There can be many sufficient sources of information, not one of which is necessary. Displayed scenes very different in appearance can afford the same information. There must be informational invariants which are perceived regardless of appearance. Things in the scene are sources of information but are not the information itself. Determining the informational invariants would be extremely useful. Making these determinations will require both creative thought and research.

Some of the most important perceptual effects of scene content occur when the scene is dynamic. It appears that the propensity for seeing in depth is an inherent characteristic of the visual system. Gibson (1966, 1979) asserts that seeing in three dimensional space is fundamental. The third dimension does not arise perceptually from the synthesis of two dimensional information; seeing in depth is an inherent characteristic of visual perception which always occurs in the absence of contrary information, i.e., that a scene is flat. Gibson's assertion is substantially supported by the work of Johansson (1975). Seeing in depth is a direct consequence of the perspective transformations that occur due to motion of the observer or of the objects that are seen. Johansson has called attention to the very important point that movement of the perceiver and objects in the world is the usual and normal state of affairs. The lack of motion, i.e., absence of transformations of the optical array is a very special and unusual case. He has shown that when a display of points or lines of light moves in a variety of regular patterns, a viewer always perceives a rigid object moving in depth. That is, an observer never sees independent movement of the elements but sees them as part of a larger structure undergoing perspective transformations.

Since visual scenes in flight simulators are always dynamic, the scene will always be perceived three dimensionally, in the absence of contrary information. Implications for investigating visual scene content issues are that producing depth per se is not a consideration as long as the scene changes according to the laws of perspective.

Information cannot be acquired from a visual scene if the sources cannot be seen. In the study by Payne, et al. (1954), a visual scene consisting of only a horizon line and a runway was successfully used to train approaches to landing. These investigators reported that the landing itself could not be accomplished because the runway outline was out of the field of view when the threshold was crossed, i.e., that there was nothing to see at that point. The implication, of course, is that there should always be sources of information visible when they are needed for the task. Information sources should therefore be spatially redundant. It is not necessary that sources for all types of information be visible at all times, as they might be present in a natural scene, but that sources for some types of information should be visible most of the time. Specifically, it seems necessary to provide sources for attitude and positional information all of the time. Objects and places need to be distinguishable most of the time and need be recognizable only if they have particular significance, e.g., being the target, the place the plane will land or a landmark for navigating a particular course.

A view of the natural ground from an airplane always contains areas which vary in form and size. Every surface of the ground plane contains smaller features and may, itself, be part of a larger feature. When the elements of an area are of no consequence as individual entities they are said to be textural elements. Texture defines a surface and gives it a solid appearance. Textureless surfaces occur only rarely in the real world. The concern here is not with the exceptional conditions, but with the usual ones. Therefore, a scene of a ground plane should afford the appearance of texture so that surfaces appear continuous and solid. Summary conclusions from the above discussion are that: 1) a groundscape or seascape should contain spatially redundant sources of information, i.e., should extend across the potential field of view; 2) surfaces should be textured to appear continuous and solid; 3) the scene should obey the laws of perspective transformation.

A scene which meets the above requirements will afford sources for almost all of the pilot's information requirements. Attitude and positional information can be acquired, as can information for altitude, direction of travel, and ground speed. These very few characteristics of the scene afford a great deal of information to the pilot. To afford all the information the pilot needs, it is only necessary to add features which allow particular places, objects and events to be recognized.

How the scene content requirements are to be met, what features should be placed in the scene, how many, how the features are to be represented, and, for all of the above, what the consequences are for accuracy of perception, are the critical research issues for scene content.

Definition of Terms

Specifying the manipulable (and constant) variables for scene content is a tricky business. Most of the variables are denoted in terms of things or the appearance of things. It is probably not possible to define the words used to discuss scene content variables with exact precision. However, it should be useful to attempt to give definitions of the important terms which will be used in the course of describing the scene content variables which are considered topics deserving research attention.

1) Texture is defined as a pattern of elements which make up a surface area. A texture element is a surface which has no identity as a thing itself. Its absolute shape, brightness (contrast with surrounding elements), and color are inconsequential as long as the element is distinguishable from other adjacent elements. Texture elements are assumed to be approximately of the same size and area.

2) Texture density means the total angular area of textural elements relative to the total angular area of the ground plane. If the ground plane is thought of as a blank background, texture density is the proportion of the background that is "covered" by texture elements.

3) Embedded levels of texture is simply the number of levels of embedded texture that can be seen. Bigger texture elements can be comprised of smaller texture elements, etc. The innermost level of texture (smallest element size), cannot be smaller than the resolution limit of the display system. Based on previous research (Carel, 1961) the largest meaningful texture element can be defined as 1/64th of the angular size of the maximum viewable area of the ground plane.

4) An area is defined as a portion of the ground plane that is distinguishable from spatially adjacent areas. It is a particular place. Like texture, the concept of area is dependent upon the pilot's need to distinguish it and his proximity, (distance and/or altitude) to it. At very far distances an area may be a texture element and therefore part of a larger area. It is probably reasonable to define the smallest size of an area in terms of its practical consequence to a pilot. For a V/STOL pilot, the smallest sized area of consequence would be approximately 50 to 100 feet on a side. A V/STOL aircraft requires an area of this size to land on. Positional information within an area can be gained by reference to adjacent areas or to the border of the area of concern. The largest area of consequence is arbitrarily considered to be 1/4th the size (in terms of visual angle) of the potentially viewable ground plane.

5) An object is anything which is recognizable or namable which is not a place or which has its recognizable character by virtue of its relationship to the ground area. An object can be located anywhere on the ground plane and still be recognizable for what it is. A shore line, for example, is not an object because it is characterized by its special relative relationship to the ground.

6) Ground plane refers to the nominal surface plane of the earth. The terms ground or ground plane are taken to include the surface of the sea or other bodies of water.

7) A place means a recognizable location on the ground. It may be recognizable because it is an area or because of the presence or positioning of recognizable objects.

8) Detail means the number of distinguishable features comprised by an area or an object. Detail is defined in terms of appearance. It does not mean, for example, the number of points, lines or edges that might be required to portray a computer generated image of the object or area.

9) Regularity and randomness are characteristics of the structure and ordering of texture elements, areas, objects, and object features. Regularity of shape means that all representations of features are identical. A repetitive ordering is the result of application of a simple rule of placement of features which is apparent to the observer. The simplicity of the rule depends on appearance, not on its conceptual simplicity. Randomness of shape or ordering means probabilistic variations.

Scene Content Research Topics

Research investigations of scene content should concentrate on those variables which are likely to have a large influence on the ability of a pilot to acquire necessary information accurately. The following are considered to be the important scene content research topics.

Representation of Texture.

1. Texture element size, density, and number of embedded levels. Texture fundamentally defines ground and object surface areas. Continuous and discontinuous changes in the gradient of texture are probably important sources of information about the extent and shape of surface (Pickett, 1968). Apparent transformations of texture due to motion of the observer, are probably sources of information for attitude, position, direction, and speed of movement and altitude. There seems to be no question that texture is necessary simply to

define the scene. Investigation of the characteristics of texture is worthwhile to determine how much texture is necessary to support accurate acquisition of information.

The amount of texture detail, whether in terms of density or number of embedded levels has important implications for visual system design. The amount of texture detail that need be available in a visual scene will affect the effort required to create a model board for a camera model-system and for the image processing power required of a CIG system. Size of texture elements can also have important interactions with display characteristics regardless of the source of the image.

The relative texture element size, texture density and number of embedded levels of texture can have important influences on perception and behavior aside from the practical problems related to creating a display. If attitude information is acquired by peripheral vision, too fine a level of texture may obviate the use of most of peripheral vision. The same problem may occur if the density of texture elements is too great. On the other hand, if the density of texture elements is too sparse, the continuity of ground or object surfaces may be disrupted and the visual field will appear to have voids, or objects will appear to float, i.e., have no definite point of contact with the ground plane (O'Conner, Shinn and Bunker, 1973).

Distance information is probably afforded by texture through motion parallax and relative size. If the texture elements do not have a known size the distance information probably comes solely from motion effects. On the other hand, if there is a known or familiar size to the texture element, they probably afford some information of absolute distance. It has been assumed that texture elements are not representational i.e., are not identifiable things but are simply surfaces which define larger surfaces. In the real world most texture is identifiable and consequently the approximate size is probably known.

The number of embedded levels of texture is an important variable for several reasons. First, visibility of texture elements is a function of the distance and altitude of the observer from the element. Near the ground, information for distance, altitude, ground speed, and vertical speed is much more critical than it is at higher altitudes. The range of levels of texture that need be visible probably changes in some corresponding fashion. Displaying fewer levels of texture at higher altitudes and more at lower altitudes probably is a reasonable strategy for conservation of display resources, particularly in a CIG system. Therefore, it seems worthwhile to investigate the number of levels of embedded texture required as a function of altitude.

2. Regularity and randomness of texture distribution. The issue of regularity vs. randomness of texture distribution addresses the consequences of variation of the arrangement of local and global ground plane structure. Should the ground plane texture be laid out in a very regular fashion and variation introduced only for definite purposes, i.e., making an area or place apparent, or should the ground plane appear random in appearance everywhere? A number of sub-issues are embedded in this question. Should texture elements have definite shape? Should they be produced by the intersection of multiple lines extending across large portions of the scene or should they appear as patches against a void background, i.e., should larger structures emerge as a consequence of the shape and arrangement of smaller structures? Should the ground plane surfaces be rectilinear, or should they have a variety of shapes?

The most repetitive and regular arrangement of texture would probably be a checkerboard pattern with smaller squares making up larger squares which in turn make up larger squares, etc. Distinctive lines extending over the entire scene would result from such a construction. It would probably be relatively easy for a pilot to acquire information afforded by perspective and perspective transformations. Relative direction and relative position information could be easily and accurately acquired. On the other hand it may be difficult for the pilot to acquire absolute positional information unless objects or distinctive areas were present in the scene. If the ground plane texture were more random in appearance positional information might be afforded whether objects and distinctive areas were present or not.

Questions of regularity and randomness of ground texture appearance are related to the critical issue topics of perceptual learning and uses of augmentation. A regularly structured texture can be considered to be a very special form of scene representation used for purposes of training effectiveness. Very regular texturing would not be representative of natural scenes. An important research question is whether or not learning to fly by reference to a scene with a very regular, and therefore unrealistic texture appearance, will generalize to real-world situations in which the pilot must fly by reference to more randomly textured scenes.

Issues of regularity vs. randomness of texture appearance involve questions of tradeoff. The primary considerations are the cost of a visual system to display the required scene, and the effectiveness of training as a result of the ground texture characteristics. A CIG scene with a high degree of regularity of texture may not appear natural or realistic, but it may require fewer edges and less programming effort to construct and, concurrently, promote effective training.

Representation of Objects.

1. Detail of representation. The need for the representation of familiar objects in a scene is easily justified. The presence and arrangement of familiar objects can establish a unique location on the ground. Familiar objects therefore afford information for ground orientation. Familiar objects also can have special significance. Obvious examples of significant familiar objects are runways, targets, and carriers or air capable ships at sea.

The amount of detail that is necessary to portray an object is an important question. It is probably necessary only to provide sufficient detail to allow the object of interest to be recognized and possibly to be discriminated from similar objects. In some cases detail may be necessary to provide a source of information about the orientation of an object, particularly of vehicles. What characteristics of an object are necessary to make it recognizable cannot be defined.

An object can be represented symbolically or pictorially. If it is pictorially represented the range of latitude of detail of representation is obviously great. Symbolic rather than representational portrayal of some objects could probably be done in many instances when it is necessary for the pilot to know only what the object is and where it is. Use of symbolic representation may result in a savings of display resources. It may also be used instructionally to emphasize the necessity of concentrating on objects as sources of information which are pictorially represented and to de-emphasize objects which are symbolically represented.

If symbolic representation conserves display resources it probably does it at the price of not providing familiar size information which may be useful for judgment of distance and altitude. If an object is pictorially represented there is probably no benefit in depicting the object with detail greater than is necessary for the object to be recognized. On the other hand, if the representation is very abstract and lacking in detail, will it as readily and accurately afford information for size and distance?

2. Number of objects required. In addition to being objects of inherent significance, and to establishing the identity of places, familiar objects are probably important sources of information for the perception of distance and altitude. Trees, for example, have a known size of between a few feet and perhaps 200 feet in height. Roads and railroad tracks have a familiar width. Ships vary in size from small boats to aircraft carriers and tankers. Even so, the shapes of ships tend to have characteristics which are associated with certain sizes.

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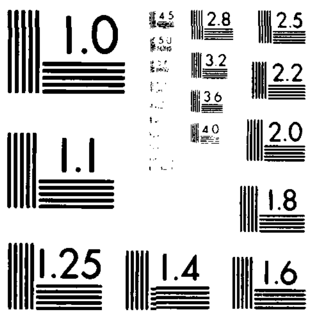
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At very high altitudes man-made objects and vegetation features become insignificant indicators of altitude and distance other than indicating that the aircraft is very high above or very distant from these objects. At high altitudes very large objects such as mountains or areas of vegetation have more significance for estimation of altitude and distance. At high altitudes, however, being able to visually determine altitude and distance accurately is not very important. Near the ground, knowledge of altitude and distance is very important. The number of familiar sized objects which can be seen almost certainly has some influence on the perception of altitude and distance.

Assuming objects are located on a textured plane and the texture itself is not of familiar size, then it is probably necessary that at least one object of familiar size be in the pilot's potential field of view. The question of how many objects need be visible to allow a pilot to maintain orientation in respect to ground position and to judge distance and altitude with the accuracy required is an open, but important question.

3. Range of sizes of objects. The range of sizes of objects that can be seen by a pilot may have an important effect on his ability to judge distance and altitude. As discussed above, relative size of familiar objects serves as a standard for the perception of size and distance of unfamiliar objects. The perceived sizes of objects in a scene are probably, in turn, important determinants of perceived distance and altitude. If there is a large disparity between the size of a familiar and an unfamiliar object, the perception of the size or distance of the latter will probably not be very accurate. A scene containing a mountain with a tower on it is an example of two objects widely disparate in size. If one or the other has an unfamiliar size, the familiar size of the other probably will not afford much information, except very grossly, about the size of the unfamiliar object.

The magnitude of the distances and altitudes that a pilot needs for accurate perception change throughout the flight. Consequently, it may be necessary to provide some range of sizes of objects in a scene to to permit continuity of perception of distance and altitude. To determine if this conjecture is true requires research. Additional research considerations are the extremes and increments of size differences that may be required. The effectiveness of objects to afford distance and altitude information may not be only a matter of the number of objects in a scene and the way they are represented. Many objects of widely disparate sizes may not afford as much information as a few objects which have their sizes distributed uniformly over an appropriate range.

Representation of Ground Areas. The pilot often must be able to distinguish and recognize locations on the ground. He must be able to distinguish different areas to maintain ground position orientation and must be able to recognize some specific areas for both navigational and mission related purposes.

Ground areas are considered to be distinct from texture because of their supposed informational purpose. Areas can afford the same information as texture but are also considered to afford information for absolute position. Texture is considered to support perception of a continuous, solid world and to afford information via perspective transformation. The information afforded by texture is relative. Areas may be textured but also have a definite size and shape, whereas texture of the ground plane can extend indefinitely. An area may be textured itself and the variation in texturing of an area would be what gives it its distinctive and recognizable appearance.

It was stated earlier that the presence of objects or their arrangement, among other things, affords information for absolute location. If texture is present and ground objects are also present, why should it be necessary to represent distinctive and recognizable ground areas? Perhaps it isn't. There is an overlap in the type of information afforded by texture, areas, and the presence and arrangement of objects in the scene.

There may be good training reasons for representing distinctive ground areas. The outline or shape of areas, depending on how they were constructed, may provide more easily usable information for direction of flight, line-up and maneuvering. It may be simpler for the pilot to keep track of the position of the aircraft in relation to some area or areas than in relationship to some object or arrangement of objects. An area as a location or place on the ground is more immediately related to a positional task than an arrangement of objects. Acquiring information that is directly related to the information required, i.e., position, with respect to an area, may be easier than acquiring information about position by first recognizing a location via the recognition of the unique arrangement of objects which establishes the location.

Also, there may be good cost reasons for considering the inclusion of distinctive areas in a visual scene. It may be expensive or technically difficult to provide complete texturing and adequate representation of a large number of objects in a visual scene. Providing distinctive areas may result in an economy of display system requirements.

Topics related to the characteristics of the representation of ground areas, i.e., size, number and number of embedded areas, appear worthy of research. These topics interrelate with other topics of scene content.

1. Size of areas. Primarily, areas are considered to afford position information. They may also usefully afford altitude and distance information once the pilot becomes familiar with their size or sizes. The required size of an area is obviously dependent upon the altitude and distance over the gound that is to be traveled during a simulated flight. An area's size should be large enough to afford position, altitude and distance information at the highest altitude that will be flown during training. On the other hand the size should not be so large that, at low altitudes, it substantially fills the view of the ground plane and thereby becomes relatively useless as a source of information. As an extreme, it is possible that only one distinct size may be necessary. Medium sized areas may be large enough to be seen at the relatively low maximum altitude that is expected to be necessary for training of V/STOL-unique tasks and small enough to afford position, altitude and distance information when the aircraft is low and is operating directly over an area. It may be necessary, however, to provide areas of two or more sizes to afford continuity of perception over a range of altitudes. The sizes of ground areas that should be represented is considered to be an important research topic.

2. Number of areas. The utility of an area to afford information to a pilot may, like objects in a scene, depend on the number of areas that are visible at any given time. The number of areas that should be potentially visible to permit continuity of perception of position, altitude and distance should be addressed as part of the scene content research.

3. Number of embedded areas. If the flight tasks require operations within a large area, it may be desirable to include smaller, sub-areas within the larger area to maintain continuity of afforded information. The use of embedded areas may also be a means of making areas readily distinct from other areas. The effects of the number of embedded areas should be investigated.

Summary

The foregoing discussion presents the general theme of research that is being advocated, i.e., the most convenient and economical way to portray a scene to the pilot that affords the required information necessary for effective training. There is no rigorously systematic way of specifying or manipulating scene content variables.

For many of the variables there are no units of measurement for a continuum and it is therefore not always possible to define "levels" of these variables without ambiguity. For example, regular vs. random distributions of

texture elements is considered to be a variable, but it is difficult to describe how it can be systematically varied. The experimenters must make a judgment call about the exact structure of the scenes when they are created.

It is likely that the scene content variables have strong interactions among themselves. The interactions are implicit in some of the definitions given earlier. For example, it is recommended that both texture and area variables be experimentally studied. If areas are large and many, the area texture could be the predominant texturing of the scene, and texture outside of these areas, as defined, becomes perhaps a meaningless variable.

It was said in the beginning that defining scene content variables is a tricky business. Scene content, however, is an important research issue area and lack of a priori ability to make neat and completely independent definitions of scene characteristics should not be a deterrent to doing research on this topic. It is important to understand what variables of a scene significantly affect pilot behavior. Part of the results of the research, it is hoped, will help lead to the development of an objective lexicon for describing scene content variables.

Table 14 summarizes the topics of scene content which are considered to have important implications for visual system requirements for V/STOL training simulators. The scene content topics will be components of the critical research issue summary statements to be presented later.

TABLE 14. SUMMARY OF SCENE CONTENT RESEARCH ISSUE TOPICS AND THEIR JUDGED PRIORITY FOR RESEARCH

ISSUE TOPICS	PRIORITY
A REPRESENTATION OF TEXTURE	
1. Element size and density	1
2. Number of embedded levels	1
3. Regular vs. random distributions	3
B REPRESENTATION OF OBJECTS	
1. Detail of representation	3
2. Number of objects	1
3. Range of sizes of objects	2
C REPRESENTATION OF AREAS	
1. Size	2
2. Number of areas	3
3. Number of embedded areas	3

PERCEPTUAL LEARNING

This category of research issue topics concentrates on the pilot's ability to learn to acquire information from the visual scene. The previous section concentrated on research topics associated with providing sources of information to a pilot that are necessary for him to perform his tasks. Providing sources of information is no guarantee that the information will be acquired. It is a virtual certainty that when a pilot first learns to fly an airplane he does not acquire all the information necessary; eventually he learns to do so. Initially, even the best display, (the real world) cannot infuse the pilot with the information he needs. The pilot must learn where to look in the outside scene, learn what to look for, and learn to make the necessary discriminations. The same type of learning must occur when a pilot learns to fly by visual reference in a simulator. Information can be available but the pilot must learn to use it.

Perceptual Learning in Flight Training

During flight training a great deal of emphasis is placed on the acquiring of perceptual-motor skills necessary to control the aircraft and on the flight procedures for executing particular types of maneuvers, e.g., takeoff, approaches to landing, landing, accelerating and decelerating transitions in the case of V/STOL aircraft, and various aerial maneuvers for navigational and mission purposes.

In flight training programs, little explicit emphasis is placed on the acquisition of visual information. During landing training, for example, references are made to the apparent shape of the runway during landing approaches and recognition of the invariate angular relationship between the horizon and the aim point. Other than this, most instruction related to visual perceptual learning takes the form of pointing out relationships of altitude and distances between the aircraft and ground points. That is, an instructor will tell a student to notice that "this is the right distance to be from the end of the runway when you make a turn", or he will tell the student to be at a certain altitude or airspeed when he is at some distance from a particular point.

Error information is often given at the moment it occurs. The student pilot is told that he is too high or too low, too far to the left or to the right, and it is up to the student to look out the window and somehow learn how the appearance of the scene is related to his correct or incorrect attitude or position. How the student is able to acquire the necessary visual information in terms of noticing the important relationships, being able to make accurate discriminations and look at the right things is unknown. Pilots must learn to extract information from a visual scene and they do. Because perceptual learning occurs apace with learning to control and

maneuver the aircraft, and because so little is known about perceptual learning, there is a lack of formal instructional effort being devoted to the perceptual side of perceptual-motor learning.

Perceptual Learning and Flight Experience

An experienced pilot learns to fly at night and during other conditions of marginal visibility where much less can be seen on a clear, bright day. Regardless of differences in the terrain or the conditions of visibility, if visual flight is possible at all, an experienced pilot can acquire the information necessary to fly safely and effectively. It is evident that the pilot's perceptual abilities are remarkably adaptive. The pilot learns to operate in a variety of visual environments and makes the correct responses in spite of great differences in the visual scene.

Perceptual Learning and Visual Simulation

Realism in Visual Simulation. In all real world flying it is assumed that a pilot can and will learn to use the information afforded by the visual scene to properly control an aircraft. It is curious, therefore, that there is so much concern about the appearance of scenes generated by flight simulator visual systems. There seems to be a great deal of fear that unless the pilot is shown a scene that is as realistic as technically possible, his flight education will be deficient and his life may be in peril when he flies the actual aircraft because he had not seen a realistic display during training. The preceding statement is exaggerated, but the driving force in visual system technology seems to be the creation of more realistic looking scenes.

It is a common practice in the evaluation of fly the simulators to have pilots experienced in the aircraft fly the simulator and make judgments and comments about the fidelity of various aspects of the simulator including the visual display (O'Conner, Shinn and Bunker, 1973; Stark, 1976). Pilots and other perceivers are very good at noticing the differences between pictorial representations and the real world. The problem is that changes are made in scene displays based on pilot criticisms because it is implicitly assumed that the training value of the scene will be improved. The pilot criticisms of display scenes and the changes made as a result of these criticisms may or may not be valid.

There are good reasons to believe that realism of scene appearance is not a valid indicator of training value. Computer generated images do not appear as realistic as most camera-model images. Yet at least one study (Thorpe, et al, 1978) has shown that the training effectiveness of both a night and a day CIG scene was greater than a camera-model scene.

Also, the Payne, et al (1954) study showed that there were great training benefits from a very simple display consisting of only a horizon and a runway.

Perceptual Adjustment to Simulated Scenes. It is well known that perceptual problems often occur when an experienced pilot flies a simulator (Ritchie and Shinn, 1973; Stark and Wilson, 1973; NAS-NRC Vision Committee, 1976; Kraft, Anderson and Elworth, 1977). These problems, evident from performance, are often verbalized as the inability to get certain cues, being distracted by anomalies in the display, or misperception of altitude and distance. Often overlooked or dismissed is the fact that in a relatively short amount of time pilots are able to adjust to the simulator's visual characteristics and to perform well. It appears that adjusting to the simulator environment perceptually is not simply a matter of consciously overcoming evident differences between perception of the pictorial display and the real world, but rather that actual perceptual learning occurs, i.e., that the pilot becomes perceptually calibrated to the visual display.

Stark and Wilson (1973) reported that during an evaluation of the Air Force Simulator for Air to Air Combat (SAAC) the pilots initially complained that because of the clarity of the distant terrain (presumably due to a lack of aerial perspective) which was made up of .5 mile squares laid out in a checkerboard arrangement, the terrain appeared to move more rapidly than seemed appropriate. The authors said "Interestingly, during the evaluation the pilots were able to compensate for this effect, and as the evaluation progressed it became less of a problem." A little later it was stated, "Perception of altitude and altitude rate was difficult for all of the pilots until they had become calibrated in the appearance of the checkerboard squares." It is assumed that these pilots had experienced no difficulties when they later returned to flying airplanes. The present authors are not aware of any reports that perceptual problems, in terms of acquiring the necessary information, have been encountered when pilots trained in simulators with visual systems went on to fly real aircraft.

The point is that just because the perceptual learning that occurs in a simulator with a visual system may be somewhat different from the perceptual learning that occurs in a real aircraft, it does not necessarily mean that a pilot will misperceive or that his performance will be adversely affected when he does fly the real aircraft.

Perceptual Learning Research Topics

Four critical research topics follow from the above discussion.

Time Course of Perceptual Learning. First, what is the time course of perceptual learning and acquiring of flight skills in a simulator as a function of the scene content? The differences between a representation and a real world scene do not necessarily have any greater perceptual and behavioral consequences than do the differences between two real world scenes. Can pilots learn to acquire the necessary information from a representational scene which may be very obviously different than any real world scene?

As mentioned in an earlier section, seeing the world as it is is a consequence of the invariant relationships between the optic array and things in the world. When the optic array is radically transformed, for example, by inverting the view of the world with mirrors, the initial perception of the world is very different from what the observer was accustomed to. Everything looks upside down. If the mirrors are worn for a number of days the observer becomes unaware of the inverted world and adapts or learns, once again, to see the world as it is. The observer sees the world and not the image of the world. If he thinks about it he is, of course, aware that his view is inverted, but most of the time he does not think about it; he simply sees the world correctly and goes about his activities. The observer in this experiment is said to have adapted. He has learned to interpret the world correctly because of the invariant relationships between the world and the optic array. It is not important how the optic array is structured as long as there is a consistent relationship between the optic array and the world (Gibson, 1979).

When a pilot enters a simulator he carries with him a way of perceiving that is appropriate to the real world. When he is confronted with a pictorial display he sees a scene that does not perfectly conform to his perceptual expectations. But, as in the experiment with the inverted view of the world, the pilot is perfectly capable of undergoing perceptual learning to correctly perceive the simulated world. During the time that the pilot is in the simulator the visual display is, for him, the real world. Since it is a training situation the question is really whether or not the pilot is effectively learning what he needs to know in order to be able to fly the real aircraft. The purpose of flight training is to teach the pilot to make the right responses (Roscoe, 1979). It would seem that it shouldn't matter what the pilot is shown in a simulated scene as long as it promotes learning to make the right responses. If the visual scene presented by a display system affords the necessary information and the pilot can perform properly, i.e., in the same way he must in an airplane, then the requirement for perceptual learning or for becoming perceptually calibrated to the simulator should make no difference.

This question is one of economics. If extra time is required because of the perceptual learning that must occur in a simulator with a relatively simple display system, is this extra time and cost of training offset by the savings on purchasing, maintaining and operating a more sophisticated display system which may present a scene requiring very little or no perceptual learning?

Transfer Effects of Perceptual Learning. A second research issue is whether there are any differences in the degree of positive transfer of training, or worse, is there negative transfer of training to the aircraft, as a function of learning to fly by reference to visual displays that are not fully representational of the real world? In other words, if a particular visual scene requires the pilot to perceive in ways that are different from perceiving the real world, will this cause any problems when he returns to flying an aircraft?

Alternate Flying of simulator and aircraft. An additional question related to this topic is what happens when the simulator and the aircraft are flown alternately? If there are negative transfer effects from the simulator to the aircraft, will repeated exposures to the simulator and aircraft environments eventually result in easy acclimatization to both or will negative effects persist?

Benefits of Formal Perceptual Training. Since a pilot in an aircraft or a simulator must undergo perceptual learning there may be benefits in terms of training effectiveness in conducting formal perceptual training. There are at least three studies which indicate that benefits could be derived from perceptual training. Payne, et al (1954) devoted a great deal of effort in their study to teaching the pilot to appreciate the importance of the constant appearance of the angle between the horizon and the aim point on the runway, sometimes referred to as the "h" distance (Bell, 1951).

Sitterley (1974) investigated the degradation of performance after one to four months of no flight activity. He used a technique called dynamic rehearsal, which was the continuous dynamic presentation of all pertinent visual and cockpit informational elements of approach and landing tasks as they occurred in a simulated cockpit environment, but without any direct interaction on the part of the pilot. Sitterley's primary finding was that the dynamic rehersal, a type of formal perceptual training, was effective for retaining flight skills without benefit of actual flight practice. He also found that the benefits of dynamic rehersal were most strongly apparent for the highly visual portions of the flight. Sitterley believes that it is the visual/perceptual elements of flight control skills which degrade over time, and postulated that the integration or coordination of far field perceptual cues was the critical element of the retraining.

Lintern (1978) investigated the effects of various strategies of using visual cue augmentation, i.e., providing artifical cues for glideslope and line-up. He found that an adaptive strategy for using augmenting cues, in which the presence or absence of the augmenting cues depends on the pilot's performance, produced better performance in the simulator than did other forms of using augmenting cues such as continuous presentation. In the adaptive strategy the augmenting cues were not present at all times. Lintern concluded that the effectiveness of the adaptive strategy was due to enhancing the pilot's ability to use the normally available cues. In other words, the use of augmenting cues was a form of perceptual training.

These three studies indicate that there are potential values to be realized from perceptual training. It seems worthwhile to investigate the value of including perceptual training as part of a more general flight training simulator program.

Therefore a fourth perceptual learning research issue topic is whether any benefits of training efficiency would accrue as a function of formal perceptual training. Could perceptual learning be speeded up or perception made more accurate by specifically pointing out certain relationships, providing supplemental information (augmentation), or presenting only those sources of information which the pilot is expected to use?

If formal perceptual training were proposed for inclusion in a flight training program, there are two obvious difficulties which would require resolution. First, is there any right thing to look at to acquire certain kinds of information? It was said that there are many sufficient sources of information, no one of which is necessary. If this is so, what criteria could be used for deciding what a pilot should be directed to look at? The second difficulty is how should perceptual training be conducted? How would verbal instruction, use of still and motion pictures or, perhaps, simulator visual scenes themselves be incorporated into the course of instruction? These difficulties are really sub-issues of whether or not formal perceptual training would be of benefit.

Summary

The four research topics of perceptual learning discussed above are summarized in Table 15. Scene content and information acquisition are parts of the same general issue of how to use visual displays in simulator training. What the characteristics of perceptual learning are, and whether they can be formally trained, are questions that can be answered concurrently with research on scene content.

It should be noted that perceptual learning topics are not indepedent variables to be manipulated but rather are questions that should be answered during the course of research on the other critical issue topics. The designs of the critical research experiments should be formulated in such a way that information can be obtained about perceptual learning processes in addition to the information that can be gained about the efficacy of scene content and display system variables.

To achieve the objectives of the most effective training at the lowest cost, it is the total cost in terms of time and money that is important. Tradeoffs can probably be made between the expense of producing scenes of a particular degree of complexity or with particular features and the ability of the pilot to learn to use the scene presented. If a highly realistic, and therefore expensive display system were specified, probably only a negligible amount of perceptual learning in the airplane would be required. On the other hand, if a lower cost system, which may not be very realistic in appearance were used, more perceptual learning in the airplane probably would be necessary. The ideal situation is to know the combination of perceptual learning requirements and scene characteristics which produces the best training results at the lowest cost.

TABLE 15. SUMMARY OF PERCEPTUAL LEARNING RESEARCH ISSUE TOPICS AND THEIR JUDGED PRIORITY.

ISSUE TOPICS	PRIORITY
A PERCEPTUAL LEARNING IN THE SIMULATOR	
1. Time Course of Perceptual Learning	1
B EFFECTS OF PERCEPTUAL LEARNING IN THE SIMULATOR ON PERFORMANCE IN THE AIRCRAFT	
1. Transfer Effects of Perceptual Learning	1
2. Alternate Flying of Simulator and Aircraft	2
C PERCEPTUAL TRAINING	
1. Benefits of Formal Perceptual Training	3

AUGMENTATION

Lintern (1979) defines augmented feedback as the situation in which information intrinsic to the execution of a perceptual-motor task is supplemented with correlated and contiguous information from additional sources. In a broad sense, visual augmentation can be considered to be any additions or manipulations of a visual scene which facilitate the acquisition of information. Under the broad definition both the addition to a scene of features which have no natural world counterpart and the enhancement of representational features would be considered augmentation. Lintern conducted an extensive review of the augmentation literature (Lintern,1979), and performed an experiment on the use of augmentation to teach approach and landing skills in a simulator (Lintern,1979). From the review and his own work he concluded that augmentation is an effective means of facilitating the training of perceptual-motor tasks.

In one sense, augmentation is used in both the real world and in cockpit instrumentation. For example, visual landing aids around an airport provide sources of information to a pilot which may not be easily acquired from natural cues. Predictor displays in an aircraft cockpit can also be considered a form of augmentation (Weller, 1979). In these cases augmentation is simply a means of providing sources of information that are more easily detected or interpreted. Use of augmentation in training, however, is intended to facilitate the learning of performance and/or the ability to use "natural" sources of information. The presumption is that the student must eventually be able to perform the tasks that are being trained without the use of the augmenting sources of information.

Lintern (1979) has concluded that for augmentation to be effective in terms of transfer of training, a performance gain must be apparent from augmentation during training. That is, pilots who are presented with an augmented display should perform better during training than pilots who are presented a display without augmentation. If there are no differences in performance during the training stage it is unlikely that augmentation will have produced transfer of training benefits. Research on augmentation could be reasonably economic if rate of learning or other performance measures in the simulator are good indicators of the effectiveness of augmentation.

Augmentation Research Topics

Substitution of augmentation for natural sources of information. Use of augmentation may allow the use of simpler and lower cost display systems because it may not be necessary to provide all representations of natural sources of information or to present them in a highly realistic form. If there are high costs associated with achieving particular

characteristics of a representational display, the use of augmentation may be able to compensate for not having these characteristics. For example, if the edge capacity of a CIG visual system limits the detail of areas or objects which can be represented in a scene, augmentation sources, which may appear very artifical, may be useful for affording the information that would normally be derived from the representational features.

Augmentation by Distortion of Scene Features. The distortion of size, shape and appearance characteristics of objects and areas could be manipulated. Such manipulations have been performed in the past for the sake of increasing training value (Ritchie and Shinn, 1973). Because of resolution limitations of the display, the CIG representation of an aircraft carrier was magnified 1.5 times to "seem about right" to the observers and to allow the carrier to be seen at a greater distance than would otherwise be possible (O'Conner, Shinn and Bunker, 1973). The carrier deck was represented in white rather than in gray to make its shape more apparent (Ritchie, 1978). The sea surface was made up of checkerboard squares and, of course, looked nothing like an ocean surface. These manipulations were made in the interest of making the afforded information more conspicuous. In effect, the scene content manipulations were a form of augmentation.

Proper Conditions for Use of Augmentation. An important task for research is to discover for which flight tasks learning is facilitated by augmentation and to what relative degree. Other than Lintern's work on the training of the landing task, very little is known about the effects of augmentation for different tasks or about how augmentation sources of information should be presented.

Strategy of Use of Augmentation. Lintern (1979) has hypothesized that augmentation will aid skill acquisition only if the student does not become dependent on it at the expense of using the intrinsic sources of information. Lintern's own data (1978) tends to support this hypothesis. When student pilots were presented with continuously available sources of information for lineup and glideslope in the simulator they performed more poorly on test trials, without augmentation, than did a group of students trained with augmenting cues that were adaptively withdrawn as performance improved. It is clear that augmentation, properly used, can enhance learning, but it is not clear whether the principal effects occur for motor learning or for perceptual learning. It is likely that both forms of learning, which are intimately related anyway, are facilitated.

Summary

It seems clear that the use of augmentation has great potential for enhancing the efficiency of flight training. The

proper form of augmentation, properly used, is likely to benefit training with any form of simulator visual scene. Because so little is known about the uses of augmentation for the training of pilot skills in a simulator, all the aspects of the use of augmentation just discussed would be good candidates for research investigation. The augmentation research issue topics are summarized in Table 16 with their judged priority.

TABLE 16. AUGMENTATION RESEARCH ISSUE TOPICS AND THEIR JUDGED PRIORITY

ISSUE TOPICS	PRIORITY
A IMPLEMENTATION OF AUGMENTATION	
1. Substitution of Augmentation for Natural Sources of Information	1
2. Augmentation by Distortion of Scene Features	3
B APPLICATIONS OF AUGMENTATION	
1. Proper Conditions for Use of Augmentation	1
2. Strategy of Use of Augmentation	2

DISPLAY CHARACTERISTICS

Topics subsumed under display characteristics are considered here to be features of visual systems which have to do with the way an image is achieved, and factors which influence the appearance of the image, and which are independent of the scene that is displayed. The display system is seen as a tool for presenting a picture. The characteristics of the display are considered to be enabling variables (Roscoe, 1979) which affect the light "signal" but do not directly have anything to do with the information that is afforded by a visual scene.

There is no question that display characteristics can have important consequences on the perception and performance of the pilot. In this report, however, not much emphasis will be given to display characteristics for two reasons. First, many of the visual system technology issues have been adequately identified and research on these topics has been planned (NTEC, 1978; Kraft, Anderson and Elworth, 1979). Second, since display characteristics are most closely related to the psychophysical aspects of vision, they are not as intimately related to behavioral consequences as are the perceptual issues addressed in the previous three categories of critical research issues. There are two topics of display characteristics which are particularly relevant to the previously discussed perceptual topics. These two visual system technology issue topics are field of view (FOV) requirements and use of color.

Field of View

There is a general consensus that a wide FOV is important for many military flying tasks and a relatively narrow forward field of view is useful only for conventional aircraft takeoff and landing maneuvers (Harvey, 1978). Two flight simulators, the Navy Aviation Wide Angle Visual System (AWAVS), now referred to as the Visual Technology Research Simulator (VTRS) and the Air Force Advanced Simulator for Pilot Training (ASPT) have the capability of very large fields of view equal to or in excess of 160 degrees horizontally and 80 degrees vertically. Field of view requirements for various flight tasks have been or will be investigated in both these facilities (Irish, et al., 1977; Irish and Buckland, 1978; LeMaster and Longridge, 1978; NTEC, 1978; Nataupsky, et al., 1979; Collyer, et al., 1980).

The field of view requirements for training of V/STOL pilots is a particularly important issue. Studies of FOV requirements for V/STOL aircraft (Clement, Heffley and Jewell, 1978; Hemingway, 1978) and the responses of AV-8A pilots interviewed during the course of this work have emphasized the need for a wide FOV to adequately perform V/STOL flight tasks.

Central and Peripheral Visual Functions. Physiologically, the light sensitive area at the back of the eye, the retina, is considered to have two distinct regions of vision, central and peripheral. The central region is characterized as having excellent resolution and color discrimination. The central one degree of vision is what is normally directed at an object of interest. That is, central vision is used to "fixate" objects and areas of interest. The peripheral region of the retina, extending outward from the central region to the limits of the field of vision, about 90° laterally, is characterized by low resolution, reduced color vision but superior sensitivity to very low light levels. Recent visual research has supported the theoretical position that central and peripheral vision serve very different purposes behaviorally and that the behavioral distinctions are at least as important, or perhaps more important, than the psychophysical differences in acuity and light sensitivity (Held, Dichgans and Bower, 1975; Leibowitz, Ginsburg and Post, 1979). The function of central vision is considered to be resolution of detail and pattern recognition. In other words, central vision tells you "what is out there." The function of peripheral vision is to detect objects entering the field of view and to provide information on "where" it is out there. An equally important function of peripheral vision is to acquire body orientation and locomotor information.

Locomotor information in terms of direction of travel and approximate rate of travel is acquired through peripheral vision from the transformation of the entire field of view. Peripheral sensitivity to movement of the entire field of view,

or optic array is remarkable. Studies of circularvection, the illusory sensation of self motion resulting from movement of the entire visual field, have shown that this effect persists until luminance is reduced to near the absolute threshold for light and is essentially independent of peripheral refractive error (Leibowitz, Rodemer and Dichgans, 1979). At very low light levels when peripheral vision still functions adequately to provide orientation and locomotor information, central vision, mediated by cone receptors, is nonfunctional. Maintenance of aircraft attitude and sensing of the direction and ground speed are functionally similar to perception of body orientation and pedestrian movements. On a very dark night a pilot, flying at low levels, could probably maintain attitude from peripheral vision, but could not see anything directly in front of him.

With these functional differences in mind, the question of FOV requirements in visual simulation should probably be regarded as two separate issues, i.e., FOV requirements to support central visual functions and FOV requirements to support peripheral visual functions.

Previous Research on FOV Size. Although FOV requirements have been the subject of past research (LeMaster and Longridge, 1978) or will be (NTEC, 1978), the studies are comparative. That is, differences in learning or performance of particular tasks are investigated as a function of display FOV. The possibility that there may be differences in FOV requirements for tasks or control functions that can be considered to be mediated either principally by central or principally by peripheral visual processes was not explicitly considered.

LeMaster and Longridge (1978) investigated the effects of FOV on an air-to-ground gunnery task using the ASPT. They concluded that no differences in performance were evident when the FOV was larger than $70^{\circ} \times 70^{\circ}$.

Milelli, et al, (1973) investigated the effects of 60°, 120° and 180° horizontal by 45° vertical FOV on terrain following, terrain avoidance and precision hovering using a helicopter as the test vehicle. A simulated cockpit was constructed in the bay of a U.S. Army CH-53A helicopter. From inspection of the data they concluded that no performance effects could be discerned for the FOVs larger than 60° horizontally. The inability to apply statistical tests to the data in the Milelli study may be partially responsible for the conclusion that no differences in performance were found as a function of FOV. Some studies (Roscoe, et al, 1966; Reeder and Kolnick, 1964; Armstrong, 1970) have shown that performance on a landing task is minimally improved, if at all, when the FOV is larger than 50° horizontally.

Collyer, et al., (1980) trained Air Force instructor pilots to make daytime carrier landings. One group was trained to make circling approaches with a wide FOV, 300° horizontal by 150° vertical. Two groups of pilots learned to make straight in or circling landing approaches with a narrow FOV, 48° horizontal by 36° vertical, and were subsequently transfer tested on circling approaches with a wide FOV, 300° horizontal by 150° vertical. No clear training advantages of the wide FOV were found.

Nataupsky, et al., (1979) trained student pilots on four tasks, takeoff, steep turn, slow flight and straight-in approach and landing. Different groups were trained with either a wide (300° horizontal by 150° vertical) or narrow (48° horizontal by 36° vertical) FOV. Subsequent peformance testing in the aircraft revealed only minor adavantages for wide FOV training on the first sortie and none on subsequent sorties. Thus there was no evidence to suggest that training with a wide FOV improved transfer of training to the aircraft.

However, on tasks which obviously place great emphasis on attitude control, which is assumed to be mediated by peripheral vision, an increased FOV is related to improvements in performance. Two recent studies (Irish, et al, 1977; Irish and Buckland, 1978) tend to support this assumption. The performance of experienced pilots was evaluated on five flight tasks as a function of FOV size, and other variables, in the ASPT. The five tasks were takeoff, Ground Controlled Approach (GCA), roll, barrel roll and a 360° overhead pattern. The FOV sizes investigated were 300° horizontal by 150° vertical, 144° horizontal by 36° vertical and 48° horizontal by 36° vertical. The general finding was that the larger FOVs were associated with significantly better performance on all maneuvers except the GCA. The performance differences were primarily associated with roll and bank control and, to a much lesser extent, with pitch control. Only minor effects of FOV were found for the GCA. The authors suggested that the FOV had minimal effects on GCA performance because the relevent sources of information were located forward of the aircraft.

Field of View Research Topics

<u>Field of View Size for Central and Peripheral Vision.</u> In general, FOV requirements for central vision translate into requirements to be able to look out the side windows of the aircraft. If a sideview using central vision is necessary it would be for tasks which demand that the pilot be able to recognize objects of significance, resolve detail, detect small movements, or make accurate judgments of lateral line-up and distance. It may be that for many tasks use of central vision to the side is not necessary beyond the limits of what is conventionally considered a forward view display, i.e., 20° to 30° to each side of center. Also, it may not be necessary to have complete continuity between the forward and side fields of

view for central vision. A virtual window (AOI) may be all that is required if there is a definite area or object where the pilot will (or should) direct his gaze. In addition, many tasks which normally would require the use of central vision over a wide area can be successfully trained with a narrow FOV (Nataupsky, et al., 1979); Collyer, et al., 1980).

A wide field of view for peripheral visual functions would be necessary if the tasks demand the ability to continuously detect attitude, attitude changes, direction of travel, changes in the direction of travel, approximate ground speed and the detection of objects which first enter the FOV from the side. Most of the information that is ordinarily considered to be picked up by peripheral vision can be detected by central vision as long as the pilot can look directly at the sources of information. The true value of peripheral vision probably becomes apparent when the pilot must use his central vision concurrently to read instruments or to look at specific objects outside the cockpit. Peripheral vision will generally continue to acquire information independently of where the pilot directs his central vision. It would be useful to know the effects of field of view size on sensitivities to, and control of, deviations in pitch, roll, yaw, direction, and ground speed changes, as a function of the pilot's central vision being primarily directed inside or outside the cockpit.

The preceding discussion suggests that one important topic for research is the determination of display FOV size necessary for training as a function of the differential importance of central and peripheral vision for providing information to perform different flight tasks. For example, FOV requirements for peripheral vision should be investigated in task contexts where control of aircraft attitude is not relatively critical, e.g., straight in, high speed approaches and where it is extremely critical, e.g., V/STOL hover. Similarly, FOV size for training of tasks which depend on the use of central vision to the side, e.g., turning or maneuvering when abeam of a specific location, or landing on a narrow deck or pad where lateral clearance is critical, should also be determined.

Scene Content in Different Areas of the FOV. Although a display device must have a FOV width and height to support the requirements of central and peripheral vision, it does not necessarily mean that what is displayed or how it is displayed need be the same over the entire FOV. Work on Area of Interest (AOI) displays has proceeded on the reasonable assumption that equal amounts of detail need not be present over the entire FOV. Peripheral vision is primarily sensitive to the "optical flow" of the world and picks up discontinuities of movement, i.e., object motion, and is not particularly sensitive to the detailed structure of the optic array, i.e., spatial relations. Therefore it may not be necessary to afford the same scene content detail in the peripheral FOV as in the central portion of the display if central vision to the side is not critical.

Also, there may be a need only for a limited amount of scene content detail but its position can be anywhere within the total field of view. In such a case it may be cost advantageous to simply superimpose scene content for central vision over that provided for peripheral vision. The Navy's new Air Combat Maneuvering Simulator (Device 2E6) portrays a sky-earth background by point-light projection of a transparency on a spherical dome with a radius of 20 feet which surrounds the cockpit. Images of other aircraft are projected directly over the background scene. Use of superimposition should be researched further to discover if specific objects or ground features, presumably of high detail, could be superimposed over a background image. The background may be specifically constructed to provide sources of information for peripheral vision which may be of low detail or completely non-representational. Discovering the required characteristics of the peripheral FOV display area to afford information for peripheral as opposed to central vision could significantly reduce display system requirements and costs.

Effects of FOV Size on Scanning Behavior. A secondary question related to FOV requirements for central vision functions is the degree to which the learning of scanning behavior is affected by the FOV of a simulator visual system. In a real aircraft a pilot learns to habitually scan the scene to detect other aircraft or, when flying low to the ground, to detect obstacles. A narrow FOV in the simulator may preclude or inhibit scanning behavior. It may be worth a small research effort, during the course of investigating other FOV topics, to discover the effects of FOV size on scanning behavior.

Summary of FOV Research Topics

The distinction between FOV requirements for central and peripheral visual functions has important implictions for research. FOV requirements for central vision are basically requirements for direct vision to the side. Central vision to the side often may not be necessary beyond the limits of what is conventionally considered a forward view display, i.e., 20° or 30° to each side of center. The primary functions of peripheral vision are to acquire information for attitude maintenance and aircraft movement (direction and speed) and to detect objects entering the field of view from the side. FOV requirements for both central and peripheral vision will probably be dependent upon the nature of the flight tasks. Those tasks in which attitude control is very important are likely to require a wide FOV for good performance. The scene content requirements for peripheral vision, however, may be very different from those for central vision. Also, the FOV size and scene content characteristics which result in best performance in a simulator may not prove to have training benefits which transfer to the aircraft. The FOV research issue topics and their judged priority for research are summarized in the top half of Table 17.

Color

Previous Research on Color. There is little question that a simulator display with color is very pleasing to pilots (Brown, 1975; Woodruff, 1979), but its utility for promoting training effectiveness is doubtful. Chase (1970) found small but positive advantages in the use of color during evaluation of display systems used for training of approaches and landings. More recently, Woodruff (1979) found no differences in learning rates or final performances by a group of 32 Air Force student pilots on an approach and landing task as a function of using a black and white or a color display. The display was a 44° x 28° forward view raster CRT system.

Display color can have effects on depth perception. There is a phenomenon known as the color-stereo effect in which, due to off-axis alignment of the optical elements in the eye, objects of different colors will appear to be at different distances. Kraft (1979, 1980) is currently investigating the consequences of this effect on approach and landing performance as a function of the color of the runway and its surround. Preliminary results indicate that field color does not have significant effects although glideslope deviations varied as a function of the different degrees of the color-stereo effect exhibited by the pilots.

Virtually all commercially available visual systems include a color capability. If a monochrome system were specifically required it would probably cost extra because it would be non-standard. For a one-of-a-kind visual system, however, color may significantly affect cost. For example, the optics necessary to provide a collimated, virtual image display which controls chromatic aberration effects and/or can selectively block or pass certain wavelengths must be more complex than the optics for a monochrome display (LaRussa and Gill, 1978). A projected, real image display, that uses light valves and provides color, must be more sophisticated than a black and white light valve system of equal resolution (Baron and Sprotbery, 1978).

Aside from enhancing the appearance of a display, color is considered useful in simulated scenes because it is an additional dimension for making objects and areas distinctive from one another (Ritchie and Shinn, 1973). In some cases, color may be the only means available for making certain objects distinctive. For example, in the real world, visual landing aids such as runway lighting, taxiway lighting, and visual glideslope indicators such as the VASI, use color to make different patterns of light distinctive or as a code for glideslope information. When a night scene of a runway is presented in a simulator display it is usually thought necessary to portray representations of visual landing aids with the same color characteristics as their real world counterparts (NTEC, 1978; Woomer and Williams, 1978).

Color Research Topics

Affording Color Information by Other Means. There may be options available for presenting the same information as that which is coded by color in a display scene. For example, although the Fresnel Lens Optical Landing System (FLOLS) on a carrier uses color to indicate to a pilot that he is very low with respect to the glideslope, the information is redundant with spatial and temporal information, i.e., the offset and flashing of the "meatball" with respect to the datum lights. Color in this case is used because of its possible attention-getting value rather than because it is the only dimension of coding that could be used.

It is one thing to incorporate color in a display scene because its counterpart in the real world is colored, and another to use color because it is the only means of affording some necessary information. In the case of visual landing aids surrounding runways and aboard ships, it may not be necessary to use color at all if the same information can be afforded by a different means even if the information is not afforded in the same way as in the real world. For example, a monochrome FLOLS would be expected to produce the same performance results as a FLOLS representation which included color. Glideslope information is provided to pilots approaching medium and small aviation capable ships by means of a tri-color glideslope indicator. The green, yellow, and red appearance of the glideslope indicator affords the pilot the information that he is either high, on glideslope or low respectively. Displays with spatial extent such as the FLOLS, "meatball", and datum arm system are not practical on smaller ships because of limitation of space. In a simulated scene of a medium or small ship, there appear to be no obvious reasons why a glideslope indicator such as the 'FLOLS' system could not be incorporated in the scene in monochrome, rather than presenting a more realistic color representation of the actual tri-color glideslope indicator. The same information could be afforded to the pilot in either case. In other words, some alternate means of affording information could be used to avoid the necessity of having a display system with color capability.

Since it is expected that V/STOL aircraft will be operating from medium-sized ships such as LHA's and LPH's, the use of simulators to train takeoff and landing maneuvers from these ships is highly probable. It seems important, therefore, to investigate whether or not displays with color are necessary to represent visual landing aids and other lighting features on ships and also in land based scenes such as night displays of runways or forward operating sites.

Use of Color for Augmentation. Color is regarded as a means for making objects and/or areas distinguishable and for coding information. Things are distinguishable because of

their brightness, contrast, shape, size, texture, position and color. If what must be seen is distinguishable without the added dimension of color, then color has no critical functional utility. On the other hand, it may be desirable to have groups of scene features distinct from others for training purposes. Augmented sources of information could be made perceptually separable from representational scene features by assigning them a unique color. Another alternative for which color may be useful would be to have the color of representational features change depending on the pilot's performance. For example, the outline of a runway or landing pad could change color depending on whether the aircraft is too high, too low or on the correct glide path. Distance information could be afforded in a similar manner.

Use of Color Highlighting for Training Purposes. Color may also be useful to highlight significant areas, objects or relationships for perceptual training purposes. Color could unambiguously define what the pilot should be attending to at any given moment. In a strict sense this use of color is a form of augmentation, but the emphasis is on making sources of information intrinsic to the scene more apparent.

Summary of Color Research Topics

Color is an esthetically pleasing feature of visual displays. It is important, however, to distinguish between using color because it is pleasing and using color because it has functional utility for training purposes. Using alternate techniques for coding informaton in a display that is normally encoded by color in the real world has been done before as has using color to emphasize certain features of a display (Ritchie and Shinn, 1973). Both possibilities, circumventing a requirement for color, and using color to highlight information sources assumed to be important deserve further investigation. The color research topics are presented in the bottom half of Table 17 along with their judged priority for research.

Summary

FOV and color were the only two display characteristics selected for inclusion as research issue topics because most of the reasons developed here for the importance of FOV and color as research topics are different from those emphasized in other discussions or research on the same topics, and because research is already either underway or planned on other display characteristics.

The distinctions between the different purposes of a wide display FOV for central and peripheral vision have not been made before. Research on FOV should take these distinctions into account. There may be alternative means for affording information normally afforded by color. The potential uses of

color for supporting augmentation and in perceptual training have not been previously addressed. Both uses of color deserve research attention.

There are other important visual system technology issues either underway or planned. NTEC will be investigating issues of resolution, contrast, detail, use of AOI displays as well as color and FOV for both CTOL and VTOL aircraft (NTEC, 1978). Kraft, Anderson and Elworth (1979) have conducted a comprehensive review of psychophysical requirements for flight simulator visual systems and have identified seven display characteristics topics which require research. These are: 1) the effects of horizontal aniseikonia on target detection and motion recognition, 2) the effect of aliasing on visual search, 3) the effect of optical magnification on perception of runway plane, 4) the effects of accommodation/convergence errors interacting with quality of displayed image, 5) the masking of scene inserts as a function of insert area and transition technique, 6) the effects of scene complexity and separation on the detection of scene misalignment, and 7) absolute brightness levels in simulators. If the results of research on these topics have important implications for the training effectiveness or cost of a visual simulator display system, they will be applicable to V/STOL training simulators as well as to CTOL and VTOL simulators.

TABLE 17. DISPLAY CHARACTERISTICS RESEARCH ISSUE TOPICS AND THEIR JUDGED PRIORITY

ISSUE TOPICS	PRIORITY
A FIELD OF VIEW TOPICS	
1. FOV Size for Central and Peripheral Vision	1
2. Scene Content in Different areas of the FOV	1
3. Effects of FOV Size on Scanning Behavior	3
B USE OF COLOR TOPICS	
1. Affording Color Information by Other Means	1
2. Use of Color for Augmentation	2
3. Use of Color Highlighting for Training Purposes	3

CRITICAL RESEARCH ISSUE SUMMARY STATEMENTS

The research issue topics just discussed have been combined into four critical research issue summary statements. Formulation of these statements was based on including in each statement as many of the topics judged to be of equivalent priority for research as possible. It seemed desirable, however, that each research statement should have some thematic coherence. That is, each research statement should include

topics or variables that seem to go together to form a general research objective. As an intermediate step in forming the final research issue summary statements, the topics within each of the four categories of topics, which were given the same priority, were grouped together to see if reasonable sets of topics would emerge.

It became immediately apparent that perceptual learning category topics were a separate class of topics from the others. The questions posed by the perceptual learning topics relate to research information that is sought as a function of the other topic variables rather than being variables to be manipulated. Perceptual learning topics affect research design measurements required, and the interpretation of results rather than choices of variables to be manipulated. Therefore, the perceptual learning topics show up in the critical research issue summary statements as experimental questions rather than as independent variables. The topic of the effects of FOV size on scanning behavior can be investigated when FOV size is manipulated for other research purposes. Therefore this topic was also considered to be an experimental question rather than an independent variable.

Some of the topics, when compared across categories, appeared to be of lesser priority, i.e., to have less potential impact on visual system functional specifications,'than others. Consequently, four groups of research issue topics were evolved from the combined topics rather than the three that might be expected to be formed as a consequence of using a three-point scale for judged research priority.

Table 18 shows the four groups of critical research issue topics that were formed. The perceptual learning topics were set to the side because of their unique status as research questions rather than research variables.

Four critical research issue summary statements were developed from the four groups of research topics. Each of the critical research issue summary statements consists of five parts: 1) independent variables (topics), 2) the experimental questions, 3) task context, 4) environmental context, and 5) a brief rationale for each summary statement. The independent variables are the variables which should be manipulated in the experiment. They are listed in each summary statement in descending order of judged importance. The experimental questions are the information that should be gained as a consequence of performing the research. The task context items are the suggested V/STOL unique tasks which are most likely to be affected by the independent variables. The environmental context items are the real-world conditions which seemed most appropriate for the recommended research. The rationale statement gives a brief overview of the general purpose of the proposed research.

TABLE 18. GROUPING OF CRITICAL RESEARCH TOPICS BY JUDGED PRIORITY FOR RESEARCH

GROUP I (Topics of highest overall priority)
1. Texture Element Size and Density
2. FOV Size for Central and Peripheral Vision
3. Number of Objects
4. Scene Content in Different Areas of the FOV
5. Number of Embedded Levels of Texture

Group II (Topics of intermediate priority)
1. Range of Sizes of Objects
2. Area Size
3. Number of Embedded Areas
4. Strategy of Use of Augmentation

Group III (Topics of lesser overall priority)
1. Detail of Object Representation
2. Proper Conditions for Use of Augmentation
3. Substitution of Augmentation for Natural Sources of Information
4. Affording Color Information by Other Means
5. Use of Color for Augmentation

Group IV (Topics of least overall priority)
1. Regular vs. Random Texture Distributions
2. Augmentation by Distortion of Natural Features
3. Number of Areas
4. Benefits of Formal Perceptual Training
5. Use of Color Highlighting for Training Purposes

Separate Class of Topics - Not independent variables
1. All Perceptual Learning Topics Except Perceptual Training
2. Effects of FOV on Scanning Behavior

A last adjustment that was made to the summary statements was the moving of one of the topics, number of areas, which originally would have been subsumed under the second or third research statement, to the first research statement. This topic seemed to be most appropriately related to ground-plane orientation variables included in the first research statement.

The four critical research issue summmary statements are presented in tables 19 through 22. These statements are presented in descending order of their judged priority for research attention. That is, the outcome of conducting the research recommended in the first summary statement is considered to have the greatest potential pay-off in terms of training effectiveness and the cost of a V/STOL simulator visual system. Also, the ordering of the four critical research issue summary statements is roughly sequential. That is, the research recommended in later statements is likely to be influenced by the outcome of the research recommended in the earlier statements. In a strict sense, however, the four research statements are independent and do not assume that the four research issues must be done in the recommended sequence.

It is beyond the scope of this effort to detail how levels of each variable should be defined, the number of levels to be investigated, or to determine what performance measures are required to answer the experimental questions. A great deal of detailed judgement is required to translate these issue statements into actual experimental designs. The experimental team, which must conduct this research and which will be aware of the practical constraints and the nature of the equipment, will be in the best position to make these judgments. These critical research issue summary statements are, in effect, guidelines which show which questions need to be answered and the direction that visual system research should take to produce the information necessary to intelligently specify requirements for V/STOL training simulator visual systems.

TABLE 19. CRITICAL RESEARCH ISSUE SUMMARY STATEMENT # 1

Independent Variables
1. Texture element size and density
2. FOV size for central and peripheral vision
3. Number of objects
4. Scene content in different areas of the FOV
5. Number of embedded levels of texture
6. Number of areas

Experimental Questions
1. How is performance affected?
2. How is training efficiency affected?
3. What is the time course of learning to acquire the necessary information for performance in the simulator?
4. Are there differences in the rate of learning for different types of information?
5. What are the positive and negative transfer effects of the independent variables on performance and the course of perceptual learning in the aircraft?
6. Is performance mediated by central and peripheral vision differentially affected?
7. What are the effects if the simulator and the aircraft are flown alternately?
8. How is scanning behavior affected by FOV size?

Task Context
1. Approach
2. Decelerating Transition
3. Rolling Vertical Landing

Environmental Context
1. Day
2. Obscuration levels
3. Forward site - unconfined

Rationale

The variables included in this statement are related to the affordance of information for orientation and guidance based on ground plane features and availability of the sources of information in the central and peripheral fields of view.

TABLE 20. CRITICAL RESEARCH ISSUE SUMMARY STATEMENT # 2

Independent Variables
1. Range of sizes of objects
2. Detail of Object Representation
3. Area size
4. Number of embedded areas

Experimental Questions
1. How is performance affected?
2. How is training efficiency affected?
3. What is the time course of learning to acquire the necessary information for performance in the simulator?
4. What are the positive and negative transfer effects of the independent variables on performance and on the course of perceptual learning in the aircraft?
5. Is performance mediated by central and peripheral vision differentially affected?

Task context
1. Approach
2. Decelerating Transition
3. Hover
4. Vertical Landing

Environmental Context
1. Day
2. Forward site - confined area

Rationale

The variables in this statement are related principally to affordance of information for distance and position perception. Approach to, and landing in a confined area is intended to have the pilot rely on objects rather than on ground texture information for orientation and guidance. Area representation variables may affect positional control.

TABLE 21. CRITICAL RESEARCH ISSUE SUMMARY STATEMENT # 3

Independent Variables
1. Proper conditions for use of augmentation
2. Substitution of augmentation for natural sources of information
3. Affording color information by other means
4. Use of color highlighting for training purposes
5. Strategy of use of augmentation

Experimental Questions
1. How is performance affected?
2. How is training efficiency affected?
3. What is the time course of learning to acquire the necessary information for performance in the simulator?
4. What are the positive and negative transfer effects of the independent variables on performance and the course of perceptual learning in the aircraft?

Task Context
1. Vertical Takeoff
2. Accelerating Transition
3. Racetrack Approach Pattern
4. Decelerating Transition
5. Hover
6. Vertical Landing

Environmental Context
1. Day
2. Night
3. LHA

Rationale

The variables included in this statement relate to the use of augmentation and color to afford information. The at-sea environment, with its natural paucity of information sources provides a good context for investigation of the effects of these variables.

TABLE 22. CRITICAL RESEARCH ISSUE SUMMARY STATEMENT # 4

Independent Variables

1. Regular vs. random distribution of texture
2. Augmentation by distortion of natural features
3. Benefits of formal perceptual training
4. Use of color highlighting for training purposes

Experimental Questions

1. How is performance affected?
2. How is training efficiency affected?
3. What is the time course of learning to acquire the necessary information for performance in the simulator?
4. What are the positive and negative transfer effects of the independent variables on performance and the course of perceptual learning in the aircraft?

Task Context

1. Approach
2. Conventional Landing and Rollout
3. Vertical Landing

Environmental Context

1. Day
2. Night
3. Conventional airfield
4. LHA

Rationale

The variables included in this statement are intended to reveal how the structure of the ground plane and formal perceptual training affect performance and the rate of perceptual learning for a high-speed landing task where turns at the proper position and acquiring of line-up, distance, and altitude information must be very accurate and for an at-sea landing task where natural sources of information are difficult to use.

SECTION VI

FUNCTIONAL REQUIREMENTS FOR THE V/STOL RESEARCH SIMULATOR VISUAL SYSTEM

CONSIDERATION OF REQUIREMENTS

This section presents functional requirements for the V/STOL research simulator visual system that are considered necessary to support the recommended research.

Generically, a visual system consists of five functional components with several fundamental options for each component. The five components of a visual system are: 1) image source; 2) image pick-up; 3) image transmission; 4) image display; and 5) image viewing. Figure 5 shows the principal options for each component and how they can be assembled to form different types of visual systems. Each potential assembly of visual system components has its own advantages and disadvantages which must be evaluated in terms of the critical research issues to be investigated, flight tasks to be performed, the flight environments, and V/STOL aircraft characteristics as shown in Figure 6.

Determining the optimal configuration of the visual system to meet the intended research purposes cannot be achieved by objective analysis methods, but must necessarily be performed by judgment of experienced specialists. The range of the research requirements the visual system is expected to support is quite large and not specified in great detail. Due consideration has therefore been given to allowing for a significant degree of versatility in the capabilities of the visual system.

The requirements for the V/STOL research visual system given here are based on the authors' experience and opinion. When possible, the specifications were based on previous research experience and/or a known requirement to support the recommended research. Practical considerations of tradeoffs between characteristics were also taken into account so that the total functional requirements could be met by visual equipment technology that currently exists or is expected to be available in the near future. For several specifications, however, there was little substantitive background information useful for determining the necessary values. In these cases the specification values are simply educated guesses by the authors.

All the specifications presented here are considered to be minimum requirements. That is, the requirements are conservative and may be less than what is achievable by current state-of-the-art, visual system technology. It was judged better to make conservative, but adaquate, estimates of the

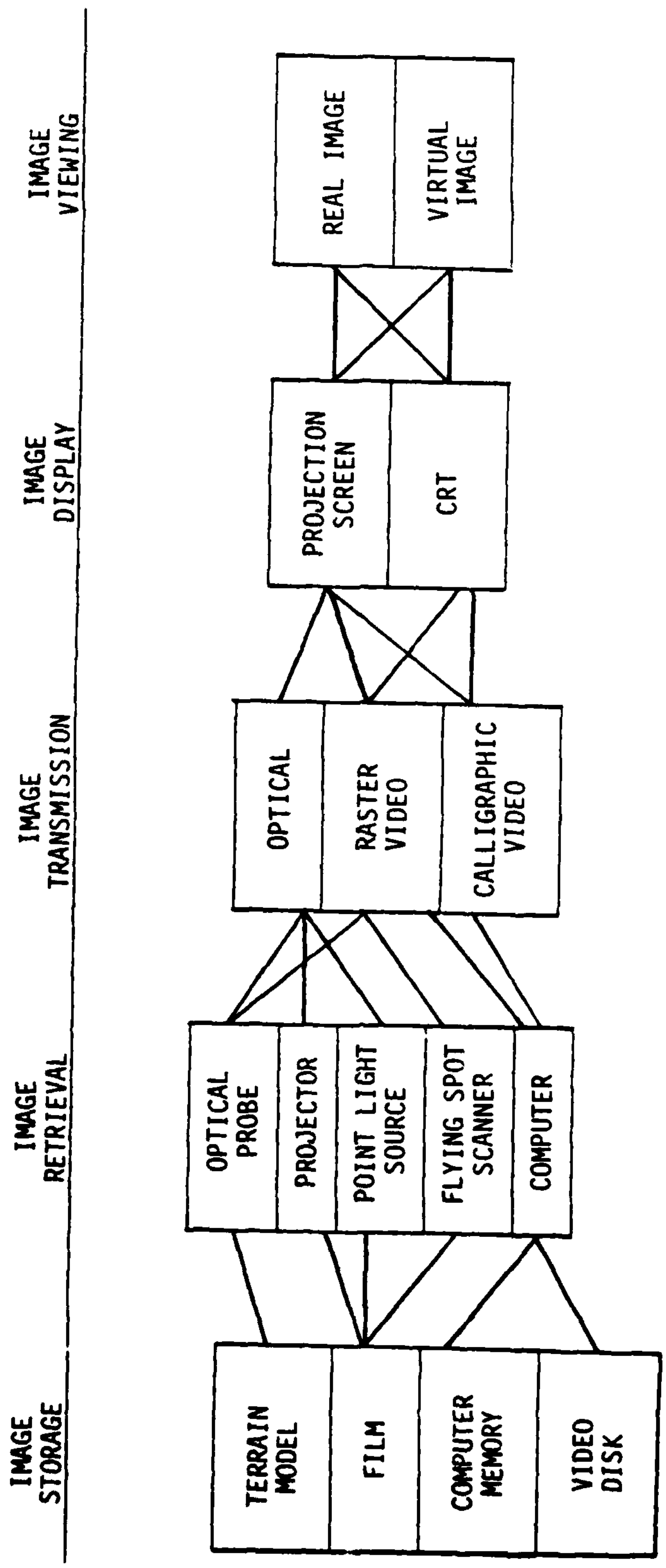


Figure 5. Block diagram of alternative visual system configurations.

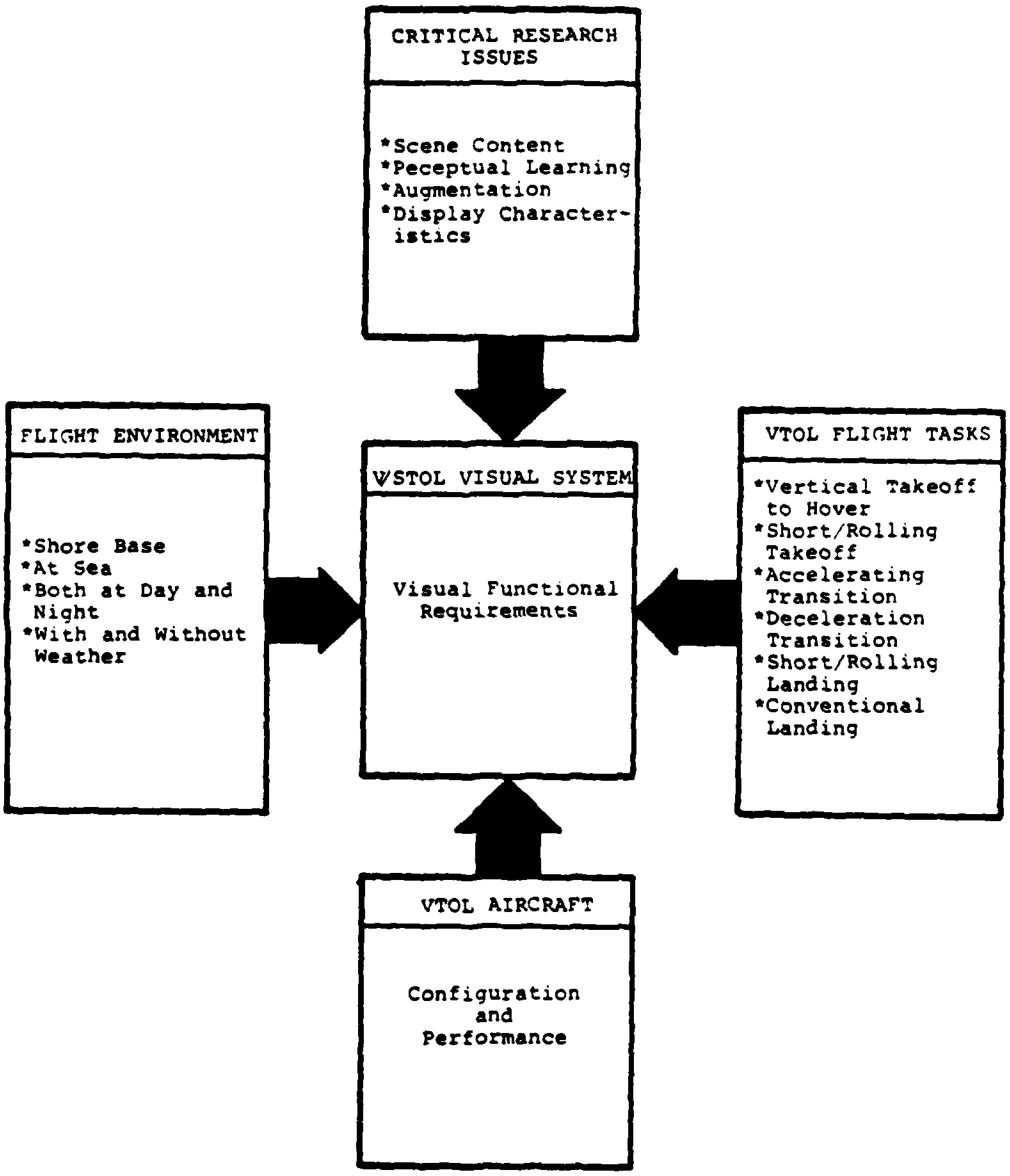


Figure 6. Factors affecting specification of functional requirements for V/STOL research simulator visual system.

functional requirements since additional research topics developed by NTEC may increase the performance requirements for the V/STOL research simulator visual system beyond those given here. If other research will be performed using the V/STOL research simulator, it will be easy to expand the specifications given here to accommodate the needs of this additional research. If the functional requirements had been specified very liberally, the research visual system would be unnecessarily expensive and it would be more difficult to modify the requirements (since tradeoff decisions would probably be necessary) to meet any expanded set of research topics.

It should be remembered that the visual system specifications given here are only those necessary to support the research topics discussed in this report. These specifications should not be considered to a set of comprehensive requirements for all flight training or research purposes. Additional characteristics or greater capabilities may be necessary or desirable for particular applications.

SPECIFIC REQUIREMENTS

Ideally, it would be desirable to state the functional requirements in a way free from any particular hardware concepts. Practically, however, the characteristics and limitations of the state-of-the-art of various visual simulation techniques must be considered.

The characteristics which adequately specify the functional requirements for the visual system are shown in Table 23. Determining the functional requirements for the visual system was initiated by establishing which characteristics are most directly associated with the experimental variables that are to be manipulated when performing the recommended research. A condensed list of the experimental variables was formed to facilitate this process. This list is shown in Table 24.

It was evident from this list that the functional requirements most related to the experimental variables are type of image generation, detail capability, FOV size, color and special effects. These are considered to be the key characteristics which determine the nature of the visual system and for specifying its functional requirements. These requirements had to be considered first. The remaining requirements are judged to be of secondary importance and were determined by considering both the requirements for supporting the recommended research and constraints which resulted from fixing the characteristics of primary importance. The descriptors were ordered in Table 23 to reflect the priority given to each characteristic for determining the nature of the visual system. The characteristics listed in the right half of

TABLE 23. DESCRIPTORS OF FUNCTIONAL REQUIREMENTS FOR THE V/STOL RESEARCH SIMULATOR VISUAL SYSTEM

1. Type of Image Generation

2. Detail Capability

3. Field of View

Color

Special Effects
    B. Obscuration
        1) Density Gradient
        2) Localization

6. Display Type

7. Maximum Angular Rates
    A. Pitch
    B. Roll
    C. Yaw   4.

8. Permissible Delay 5.

9. Resolution

10. Maximum Luminance

11. Contrast

12. Update Rate

13. Positional Accuracy

14. Maximum Distortion

TABLE 24. CONDENSED LIST OF EXPERIMENTAL VARIABLES WHICH MOST AFFECT THE SPECIFICATION OF THE FUNCTIONAL REQUIREMENTS FOR THE V/STOL RESEARCH SIMULATOR VISUAL SYSTEM

1. Scene Features (number, distribution, form of representaton)
    A. Ground Texture
    B. Objects
    C. Areas
    D. Augmentation
        Additional features
        Highlighting
        Distortion of scene features

2. FOV Size

3. Scene Content by Location in FOV

4. Use of Color for Augmentation

5. Meteorological Conditions
    A. Day
    B. Night
    C. Obscuration
        Density gradient
        Location

the table are considered to be of primary importance and those listed in the left half of the table are considered to be of secondary importance.

Primary Requirements

Image Generation. Because the V/STOL simulator visual system will be used for research purposes, flexibility of use is an important general requirement. Several of the research issues require changes of scene content, the addition of various kinds of augmenting features, the alteration of FOV size, and different scene content in different parts of the FOV. It is doubtful that either a film, model board or video disk image generation system could afford the flexibility required for the research. A CIG most definitely seems to be the image generation system most amenable to the research requirements.

Detail. The amount of detail in a scene that can be produced at the required image update rate by a CIG system is usually stated in terms of the number of primitive elements that can be processed. The nature of the primitive element is dependent on the design of the visual system hardware. Usually, an edge is defined as the primitive element although points or geometric solids have been named as primitive elements. Here it is assumed that an edge is the primitive element.

The ability to manipulate the scene content features, i.e., ground texture, objects, and areas, is necessary to support the recommended research. The number of displayable edges required is difficult to determine because it is so dependent upon the specific modeling of the scenes. The scene modeling will take place when the research program begins.

To estimate the minimum number of edges that can be displayed the requirements for ground plane texturing, and the construction of objects and areas were considered to be separate requirements. To generate ground texture by CIG could easily require several thousand edges and make the image generation system very expensive. It is therefore recommended that ground texturing, including rises, depressions and hills (if possible), be accomplished by special purpose hardware and the CIG be devoted to construction of areas and objects. The texturing hardware should have some flexibility to allow the detail of the texture to be varied, i.e., the number of contrast levels of the texture and the spacing of elements. Using special purpose hardware for texture generation will absorb only a small amount of the processing capacity of the image generation system.

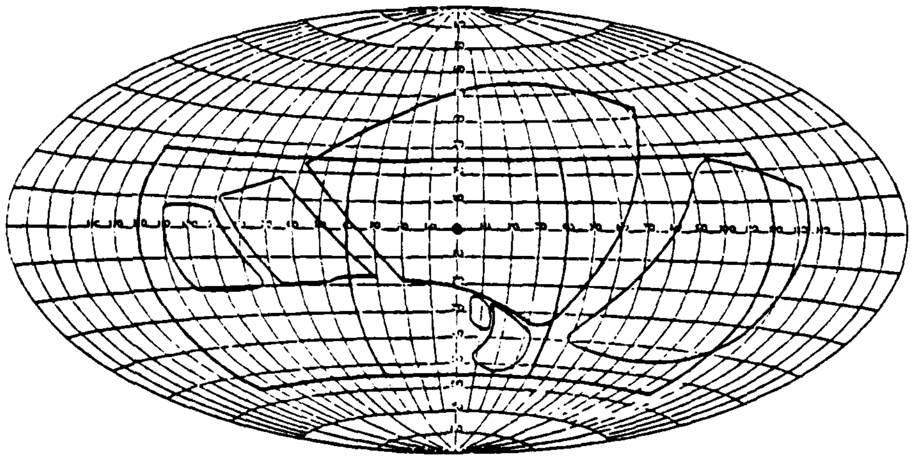
Based on one of the author's impressions of the complexity or detail in CIG scenes with different numbers of displayed edges and the nature of the recommended research, it appears

that the ability to process and display scenes with a maximum of 2000 edges will be sufficient for research purposes. If the image generator could handle a larger number of edges there is little doubt that they would be used, but the necessity of producing scenes requiring more than 2000 edges is doubtful. Using special purpose hardware to generate ground texture and having the ability to model objects and areas with 2000 edges should satisfy all the research requirements.

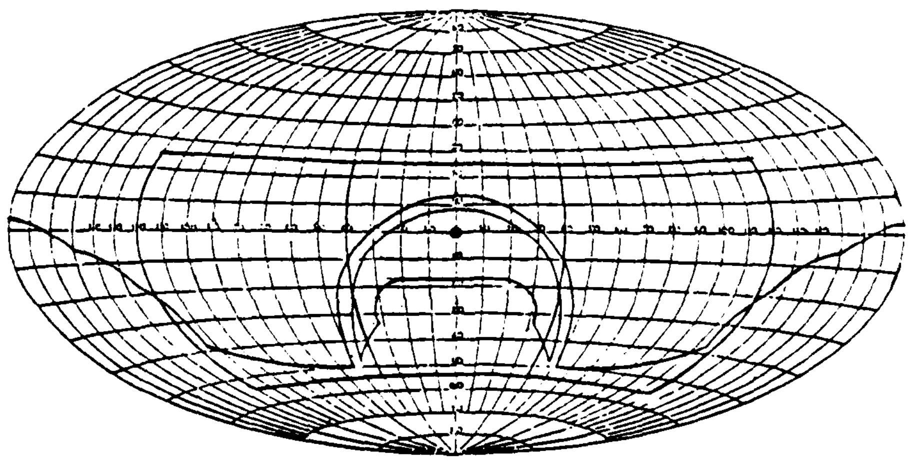
<u>FOV Size.</u> Since FOV size and scene content in different parts of the FOV will be research topics it would be ideal to have a display FOV as large as that of V/STOL aircraft. This would require a very extensive FOV. Reference to the diagrams of FOV size for V/STOL aircraft presented in Figure 7 gives some appreciation of how extensive the ideal FOV would be. Since there are no operational Type-A V/STOL, the top half of Figure 7 shows the FOV for a Sikorsky S-76 helicopter as seen from the pilot's position. The helicopter FOV is probably a reasonable representation of the FOV than could be expected in future Type-A V/STOL aircraft. The bottom half of Figure 7 shows the actual FOV for the AV-8B, Type-B V/STOL aircraft. The total horizontal FOV in both cases is approximately 220° and the maximum vertical FOV extends approximately 50° below the line of sight and from 55° to more than 90° above the line of sight.

However, to support the recommended research a FOV size equivalent to that of actual V/STOL aircraft is not considered to be necessary. A FOV of 180° horizontally and 80° vertically is considered adequate to support the recommended research. A vertical FOV above the line of sight of 30° is considered adequate because there will be few instances when any scene content will be present above this elevation angle. On the other hand, a vertical FOV extending 50° below the line of sight is necessary since questions about the importance of ground texture and areas for tasks such as hovering should allow for scene content in the FOV as close to the aircraft as it is possible for the pilot to see. The instantaneous 180° by 80° FOV should be positionable in a larger, total FOV of 240° horizontally by 100° vertically. The instantaneous FOV should be positionable vertically 50° above and below the line of sight.

<u>Color.</u> The third and fourth critical research issue summary statements impose a requirement for color as a means of separating augmentation information from scene information or highlighting scene information. A single color in addition to black and white would be sufficient for this purpose. However, since the ability to generate and display colored scenes is commonly incorporated in standard image generation and display equipment it is doubtful that there would be any significant economic benefit in procuring a visual system with only one color besides black and white. Also, it is likely that other research, not proposed here, would require the



Estimated FOV for Type-A V/STOL



FOV for Type-B V/STOL (AV-8B)

Figure 7. FOV for V/STOL aircraft.

ability to generate full color scenes. Therefore, it is recommended that the visual sytem for the V/STOL research simulator have a full color capability unless there is a significant cost difference between a single color system and a full color system.

Special Effects. The visual system should be capable of generating both night and day scenes. In addition, it should have the ability to generate atmospheric obscuration effects. The gradient of density should be adjustable to vary the "thickness" of the simulated haze/fog. This capability is inherent in almost all modern CIG systems. It would also be desirable to contol the location of the obscuration. That is, it should be possible to have obscuration only in either the central or peripheral parts of the display. Obscuration which could be localized would provide a convenient means for manipulating the useful field of view and the amount of visible detail without the presence of a sharp edge at the limits of a reduced FOV. The reduction of detail by obscuration will also facilitate the investigation of the differential processes of peripheral and central vision in acquiring information required to perform flight tasks.

Secondary Requirements

The above requirements define the basic nature of the visual system necessary to conduct the recommended research. The following requirements, while important to more fully characterize the visual system, are considered secondary in the sense that some latitude in these requirements is possible without compromising the ability of the visual sytem to support the research program. In the development of the following requirements some attention was given to what can be practically achieved with current state-of-the-art visual systems.

Display Type. The choice of display type, either virtual image, or a real, projected image, is probably more dependent on cost considerations than on the research support requirements. A real, projected image display undoubtedly would cost less than a virtual image display. The chief functional difference between the two display types is the distance at which the image is viewed.

A large effort has been expended on the development of virtual image displays. A virtual image display presents the image at, or near, an infinite optical distance from the pilot's eyes. Few virtual image displays have collimation errors of less than .03 to .05 diopter, equivalent to an image distance of approximately 50 to 100 feet. One of the common uses of a virtual image display is presenting the same scene to two pilots seated side by side, when required. It should be noted that both pilots normally see the same scene. That is, the point of view is the same whether viewed from the pilot's or co-pilot's position.

An additional advantage of a virtual image display over a real image display is the minimization of parallax errors. That is, there is less error in the apparent displacement of near field and far field objects when the pilot moves his head from side to side. In a real image display all images, regardless of their perceived distance, are actually located at the distance of the projection screen which is typically between ten and twenty feet from the the pilot. The images of both apparently near and far are displaced at the same amount, i.e., about 2.8° with a six inch head movement. In a virtual image display the same amount of head movement would produce an angular displacement of only about .3°. Since, in the real world, most objects seen outside the cockpit are 30 or more feet distant from the pilot's eyes, the amount of parallax produced by head movement is very small and more realistically represented in a simulated scene by a virtual image display rather than a real image display.

Experience with Northrop's VTOL simulations using a real image distance of 12 feet, however, proved to be very effective for supporting the performance of VTOL tasks, such as percision hover and STOL landing, which are very dependent on external visual cues. Since the recommended research does not involve tasks requiring two pilots and a real image display system is less costly (particularly for a color display) than a virtual image display system, the use of a real image display system for the V/STOL research simulator is recommended.

The recommended FOV size is 180° horizontally by 80° vertically. Either a virtual image or a projected real image system would satisfy the research requirements. Real image projection is suggested because it is probably a less expensive method. Three projection channels, each with a projected field size of 60° horizontally and 80° vertically, placed side by side, would form the recommended FOV size. Special projector lens optics may be necessary to produce the desired FOV for each channel and to minimize scene distortion.

Given that the research would involve only single pilot tasks, a real image display system would be used and the FOV would be 180° horizontally by 80° vertically, then the most practical screen shape would be a sphere centered at the pilot's eye position. A spherical screen with a radius of ten feet, as used on the existing VTRS CTOL simulator, would be acceptable, but a spherical screen with a radius of 15 feet would simplify some of the practical problems of constructing the visual system such as distortion correction and obtaining projection clearance around the cockpit for the desired 50° vertical FOV below the line of sight.

<u>Maximum Angular Rates.</u> The maximum angular rates are the rates at which the simuated aircraft appears to rotate with respect to the portrayed scene in pitch, roll and yaw. In

effect, it is the rate of change of the scene. This characteristic is important if a partially mechanical visual system, such as a camera-model board system, were to be used. The speed at which the camera would be required to rotate to simulate aircraft rotation would affect the design of the camera-gantry system. Since a CIG system has been recommended, maximum angular rates are of little functional importance but will be given in the event an image generation system other than CIG is specified. The required rates are based on the maximum apparent rotation that might occur in the aircraft failure mode, i.e., out of control. The required maximum rates are 50°/second for pitch and yaw, and 100°/second for roll.

Permissible Delay. A CIG image requires updating because of changes in attitude or position of the aircraft. When the pilot makes a flight control input, the simulator control computer must calculate the response of the aircraft to the control movement. Once the aircraft response is calculated, this information is passed to the image control computer which then produces an appropriately updated image corresponding to change in the eyepoint as the aircraft moves along. Computation of the aircraft response and the new image can take an appreciable amount of time. Consequently, there often is a delay between when a control is moved and when the effects are seen in the displayed image.

In current CIG systems, a total delay between a pilot's control input and response by the visual system ranges from approximately 100 to 200 milliseconds (Ricard et al., 1976). These delays can result in the pilot overcontrolling the aircraft and the impression that the aircraft is unstable. Ricard and Puig (1977) reviewed available research findings and, combined with their considerable knowledge of the effects of image delays, concluded that image delays should not exceed 83 to 125 milliseconds, although longer delays may be acceptable for certain flying training tasks. They present data in their report which show that acceptability ratings of a display are high if the delays are 175 milliseconds or less. Delays beyond 175 milliseconds result in a constant decrease in display acceptability ratings with increased delay time.

Based on the above information the desired maximum permissible delay is 83 milliseconds. If, however, this is not technicallly achievable, a maximum permissible delay of 125 milliseconds would be acceptable. These fairly conservative delay limits are based on the belief that in highly demanding task situations the performance of V/STOL aircraft pilots may be affected by longer delays.

Resolution. Resolution is the minimum angular separation that can be seen. Display resolution is typically quoted in terms of minutes of arc per line pair. In effect, one minute of arc visual resolution is equivalent to two minutes of arc per line pair resolution. The resolution limit of the human eye is

nominally about one minute of arc. Resolution depends on optical and electronic characteristics of the display system. In general, resolution near the center of a display is better than it is at the extreme edges. So, in practice, the theoretical resolution achievable by a display is almost never realized. Most simulator visual sytems, therefore, do not have a resolution value which is applicable over the full field of view. As a general statement, however, current simulator visual systems have a resolution range somewhere between six and 30 minutes of arc per line pair. The higher resolutions are usually achieved only with special, inset displays which have a variable size. Their maximum resolution at the smallest size is about two minutes of arc per line pair.

It is easy for pilots to detect that a simulated scene does not provide resolution equal to the resolving power of their eyes. In the real world obscuration and low light levels, such as occur during dawn and dusk, significantly limit the ability of a pilot to resolve detail. Under these circumstances, however, a pilot is still able to perform his flight tasks, particularly takeoff and landing, despite the fact that he is working with reduced acuity. How much scene resolution is necessary to perform V/STOL tasks is an open question but not one to be addressed in the presently recommended research. Effects of different levels of detail of ground plane texture and objects may be affected by the resolution of the scene. It is therefore desirable to provide a scene with as much resolution as is practical and consistent with achieving the primary requirements for the V/STOL research simulator visual system. It is recommmended that the visual system have a limiting resolution of twelve minutes of arc per line pair (six minutes of arc visually). This level of resolution should be adequate to support the investigation of the research issues.

Luminance. The luminance (brightness) of a scene will affect the amount of contrast that can be detected, the level of detail that can be resolved, and the discrimination of color. Above approximately one foot-Lambert (fL) luminance, human visual performance increases very gradually with increasing luminance. For this reason and because it is technically difficult to provide a level of luminance greater than a few fL over a wide FOV, it is recommended that the visual system be able to provide a maximum luminance of at least one fL. A higher maximum luminance would be desirable but is not considered necessary to support the recommended research.

Contrast. Contrast is the difference in luminance between two features or areas in a scene. It is the basis for visual acuity and the ability to distinguish the components of a scene. The contrast sensitivity of the eye is primarily dependent upon the luminance level of the scene and feature size. The maximum contrast that can be generated by a visual

system depends on the characteristics of the image generation and display equipment. Modern visual systems have the ability to provide an adequate range of contrast for most simulation purposes.

Most projection displays have the capability to produce contrast ratios from 15:1 to 50:1. When a spherical projection screen is used, the effective contrast is reduced because of internal reflections within the sphere. The cure for this problem is to use a high gain screen. The requirement for a large FOV, however, will necessarily involve large, off-axis projection angles which are likely to preclude much contrast improvement from the use of a high gain screen. Past experience with various spherical projection screen displays indicate that, even with a unity gain screen a contrast ratio of better than 20:1 can be achieved. This contrast ratio is typical of very good quality commercial television displays and will be adequate for supporting the recommended research. It is therefore recommended that the V/STOL research simulator be capable of generating a maximum contrast ratio of at least 20:1.

Image Update Rate. Raster displays typically generate two interlaced fields of half the total displayed raster lines at a rate of 60 Hz to produce a full frame rate of 30 Hz. Since control of V/STOL aircraft near the ground may involve small, quick movements of the aircraft, a rapid image update rate will be desirable to minimize the appearance of jitter and image doubling. It is recommended that the visual system be capable of an image update rate 60 Hz. This rapid image update rate will also minimize the chances of any apparent flickering of the display in the far peripheral field.

Positional Accuracy. Positional accuracy is the minimum change of position of the aircraft that is apparent from a change in the displayed scene. A V/STOL unique requirement is the ability to detect small changes in ground position during hover and ascending and descending from hover. The pilot's eyes at a nominal hover height will be approximately 30 feet above the ground. With a downward view angle of 45° the pilot will be able to see the ground at a line-of-sight distance of about 43 feet. Assuming, conservatively, that the pilot can detect a displacement rate, or angular change rate, of $.2^{\circ}$ per second, the display must be able to show smooth movements for changes as small as 2 inches per second. In effect, the position of the aircraft with respect to the displayed ground plane must be determined within two inches of accuracy. It is therefore recommended that positional accuracy of the visual system be at least two inches.

Geometric Distortion. Geometric distortion is the degree to which the displayed angular relations in an image depart from those dictated by the laws of perspective. Distortion is most typically measured by displaying a rectilinear grid and

determining the maximum displacement of points on the line with respect to their intended postion. The maximum difference between the actual and intended line position is expressed as percentage distortion.

Past experience has shown that geometric distortion in excess of 5% is usually noticed and distortion of less than 2% is rarely noticed by experienced pilots. It is therefore recommended that the V/STOL research simulator visual system be limited to a maximum of 2% geometric distortion.

Summary of Functional Requirements.

The functional requirements for the V/STOL research simulator visual system are summarized in Table 25. These requirements are applicable to all four Critical Research Issue Summary Statements (CRSS) shown in Tables 19 through 22. There are, however, a few exceptions to the requirements for some of the CRSS.

Exceptions to Functional Requirements.

Color is not required to perform the research recommended in CRSS #s 1 and 2. Obscuration is not required for the research recommended in CRSS #s 3 and 4.

TABLE 25. SUMMARY OF RECOMMENDED FUNCTIONAL REQUIREMENTS FOR V/STOL RESEARCH SIMULATOR VISUAL SYSTEM

1. Type of Image Generation	
A. Scene objects and areas	CIG
B. Ground Plane Texturing	special purpose hardware
2. Detail Capability (CIG)	2000 edges
3. Field of View	180° H x 80° V
4. Color	3 color desired; 1 color plus B&W necessary
5. Special Effects	
A. Day - Night	selectable
B. Obscuration Density Gradient	controllable
C. Obscuration Localization	controllable
6. Display	
A. Type	3 projectors
B. Screen Shape	spherical
C. Screen Size	15 ft. radius desired; 10 ft. radius minimum
7. Maximum Angular Rates	
A. Pitch	50°/sec
B. Roll	100°/sec
C. Yaw	50°/sec
8. Permissible Delay	83 msec desired; 125 msec maximum
9. Resolution	12 arc min/ln pr, 6 arc min, visual
10. Maximum Luminance	1 fL minimum
11. Contrast	20:1 minimum
12. Image Update Rate	60 Hz
13. Positional Accuracy	2 inches, mimimum
14. Maximum Distortion	2% geometric maximum

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